



Multi-Layer, Multi-Domain Network Control for Agile Service Providers

Overview

SD-Core unifies network controls from the access, to the edge, to the datacenter, and through the core.

By merging all legacy and programmable resources, SD-Core removes network silos to improve efficiencies and streamline security while enabling programmability and automation.

- Reduced time and effort to integrate a new equipment vendor into your IP/MPLS network increases commercial tension and lowers CAPEX
- Reduced software footprint to have a single controller for both optical and packet domains
- Reduced time to provision a new customer
- Reduced time to define and launch a new service
- Increased efficiency in bandwidth utilization across the domains
- Ability to define and support more types of services to be more competitive and innovative

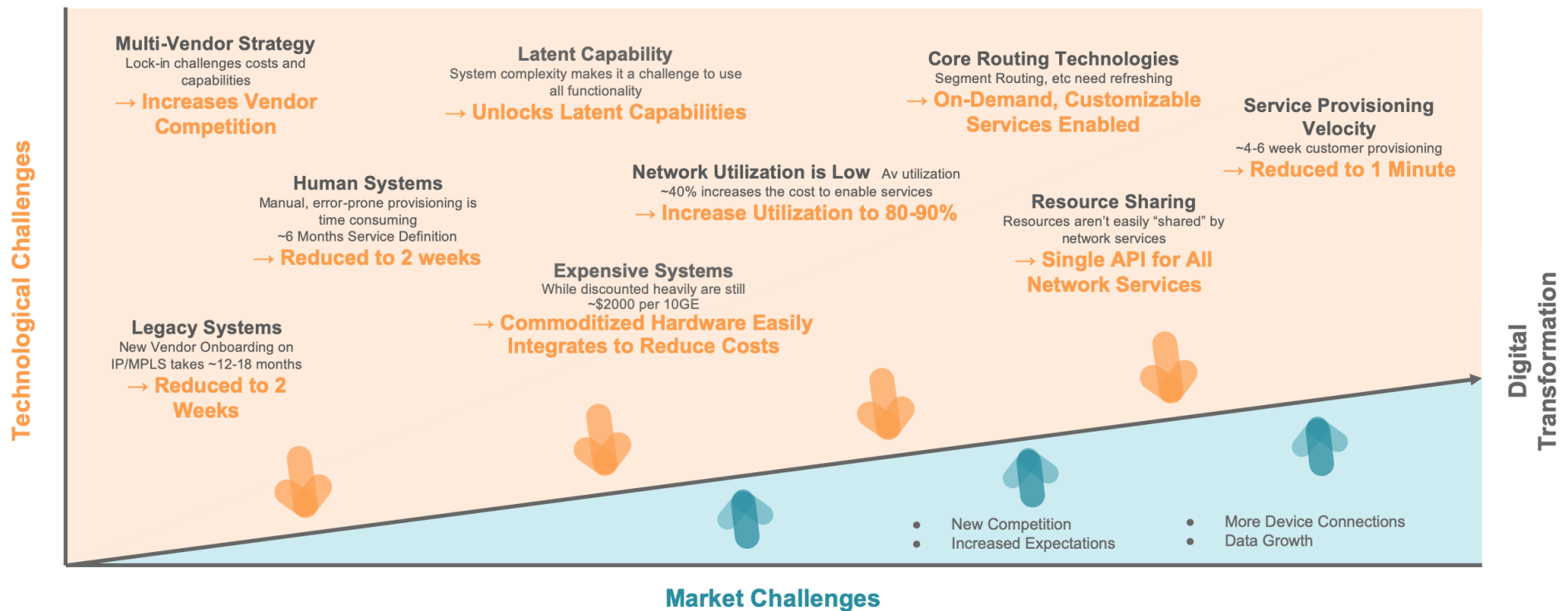


Background

The communications industry has long identified a need to keep pace with the dynamic market place by transforming the way it builds and operates its networks. While Service Providers (SPs) are elbow deep in their transformation initiatives to keep pace with the dynamic marketplace, there are several technological challenges holding up progress of the digital transformation. Some of these challenges are easier to solve than others, but there are a few key areas which the market has discovered are particularly challenging.

One of these challenges is the requirement to control all network resources, across multiple domains (administrative domain, network domains —

access, backhaul/aggregation, core, IP/Openflow network) and multiple layers (network layers, i.e. packet switching, optical transport), in a unified manner. This capability is required for any fully automated, closed-loop, intent-driven network which needs to deliver on-demand, customizable services with 3 to 5x efficiency improvements — the goal of nearly every SP digital transformation. One thing which complicates this multi-layer, multi-domain capability is the integration of existing infrastructure with new network equipment and ubiquitous software control. Historically, most SPs have held a dual-vendor strategy when it comes to network equipment — one or two types of vendor equipment for the Provider Edge (PE) and





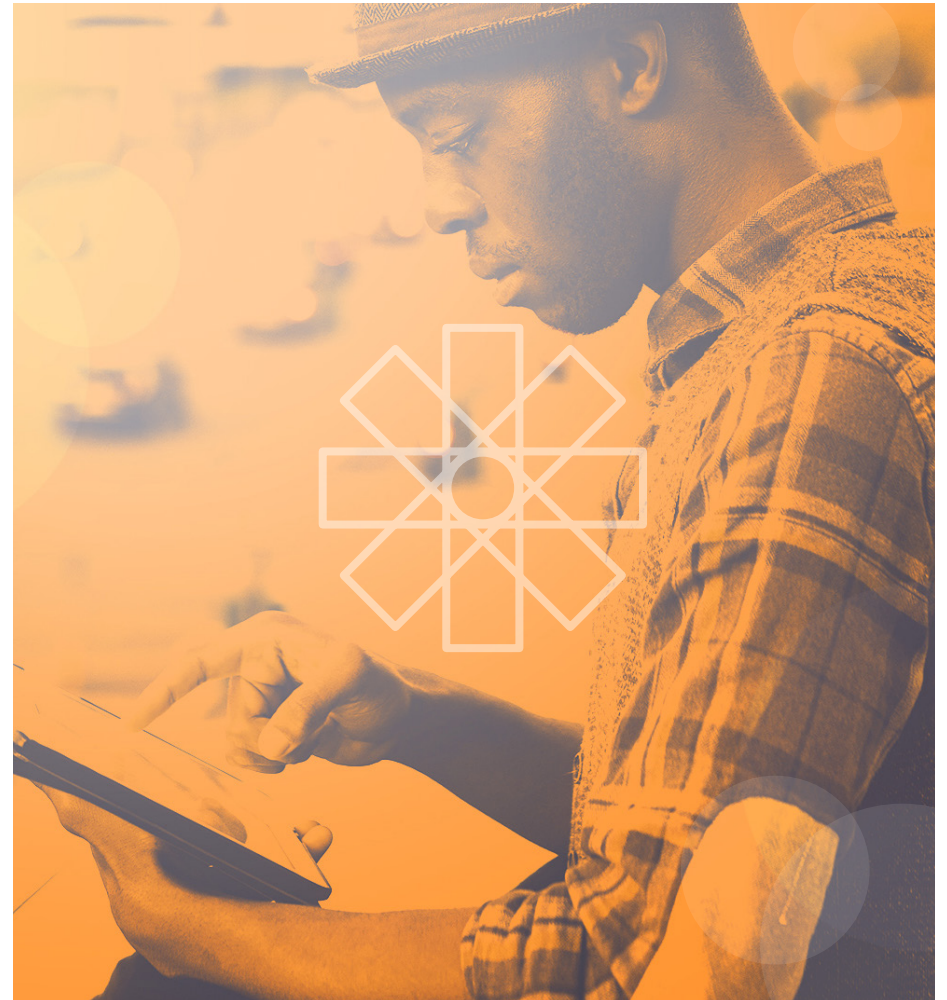
one to two vendors for the core. The time to add a new vendor to OSS can take 6-12 months, which keeps the vendor numbers low. With these complications in mind, some SPs had chosen to control their legacy and modern network resources in silos. Moving into an era of rapid service innovation and on-demand customer requirements, however, the ability to provide centralized software control to automate and enable new multi-vendor service delivery end-to-end is non-negotiable.

Another challenge impacting SP transformations is network utilization. With most current network utilization below 40%, there is a lot of very expensive latent capability. Specifically within MPLS networks, network structure has been kept simple and utilization low in order to maintain carrier-grade performance due to manual processes and rudimentary systems. Every time a network is manually touched is an opportunity to incorporate errors and create damage, and systems have limited static data; hence over-provisioning capacity has been the methodology of choice. Moving toward software-driven networks will unleash the excess capacity and engage network functionality originally believed to be too complicated for production.

Beyond under-utilized legacy networks, the next challenge SPs face is that of core routing capabilities. Current technology can't keep pace with the needs of a digital era — RSVP and LDP are reaching protocol scaling limits which leads SPs to consider huge infrastructure refreshes with segment routing. When coupled with the non-deterministic nature of legacy networks and the lack of a single arbiter, updated routing capabilities in NextGen heterogeneous networks becomes complicated.

Hampered by technical challenges, SP digital transformations are also being impacted by the constraints and high costs of being locked into vendor ecosystems. This lock-in means SPs network roadmaps are in the hands of third-party vendors — and rolling out new capabilities on vendors' timelines instead of their own. As traditional equipment vendors acquire software and offer a limited version of network control, the risk to the SP increase from

the additional lock-in created as equipment vendors gain power over the software control layer. Those with the foresight to seek true transformation have had enough; separation at the software control layer will be the only way to drive commercial tension with network equipment vendors. Freedom from vendor roadmaps will open up a new paradigm in efficiency and service innovation.

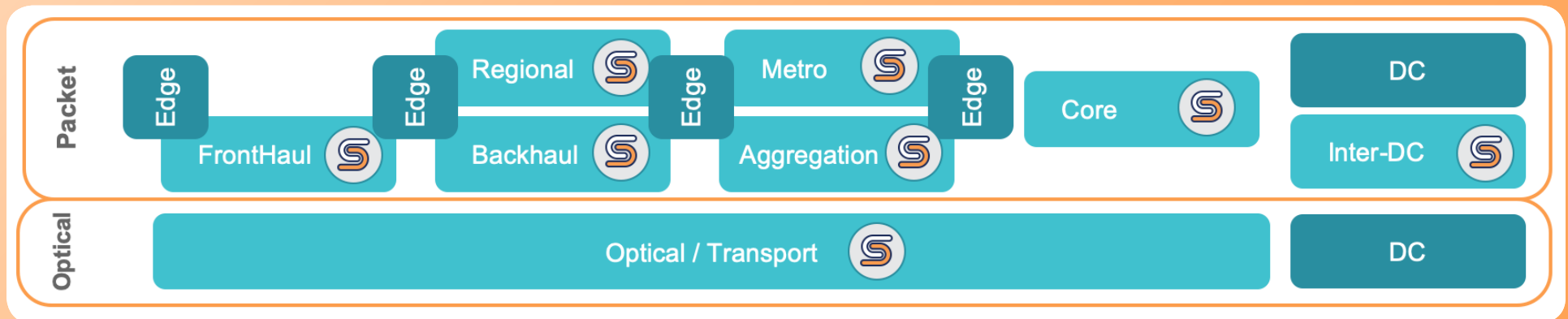


End-to-end Automation for Transforming Networks

Software-Defined Core (SD-Core) is an open source-based solution which returns network control to the Service Provider and enables future-proof service agility.

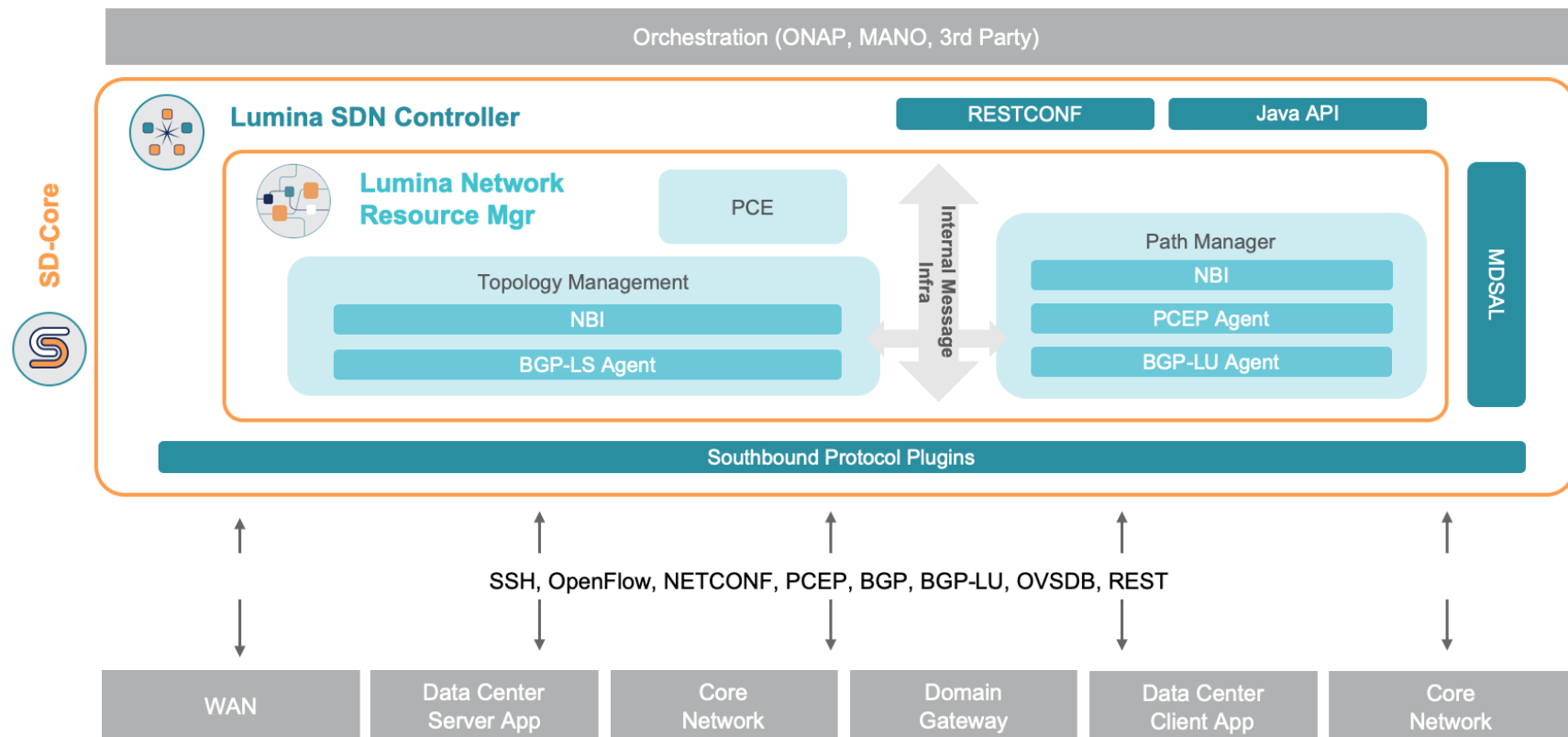
SD-Core leverages next-generation SDN architectures to provide end-to-end network visibility. These next-generation architectures revolutionize network capabilities by unifying network controls from the access, across

edges, to the datacenter, and to the core. By merging legacy, cloud and programmable resources, SD-Core removes network silos to improve efficiencies and flexibility. An important part of SD-Core, automation enables efficiencies which are unattainable in current network architectures. Beyond automation however, SD-Core — with PCE, topology learning, and combined services and infrastructure (path) provisioning — provides control beyond simple management.



End-to-End SD-Core Enabled Control

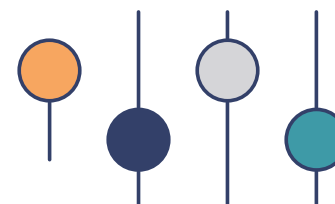
The Illustration below shows the breadth of SD-Core in a transforming network. Components of this architecture are described in the “Lumina SD-Core Products” section to follow.



Moving beyond proprietary normalization, which keeps SPs locked to their vendors, SD-Core uses a standards-based approach to network control. SD-Core creates flexible control across all network layers, domains, and vendors using YANG models for topology abstraction and path computation. With vendor-neutral models and standardized protocol interfaces, the solution abstracts and unifies all network control plane operations. With a wide range of metrics, algorithms and network & non-network constraints, SPs can dynamically engineer traffic and control disparate resources to unify networks, and enable capabilities like network slicing.

As a programmable underlay, SPs don't need to ensure that their networks are 100% available with low latency at all times. While overlays will simplify many things from an application standpoint, they will not provide the programmability necessary to support the WAN, which SD-Core as a programmable underlay fulfills.

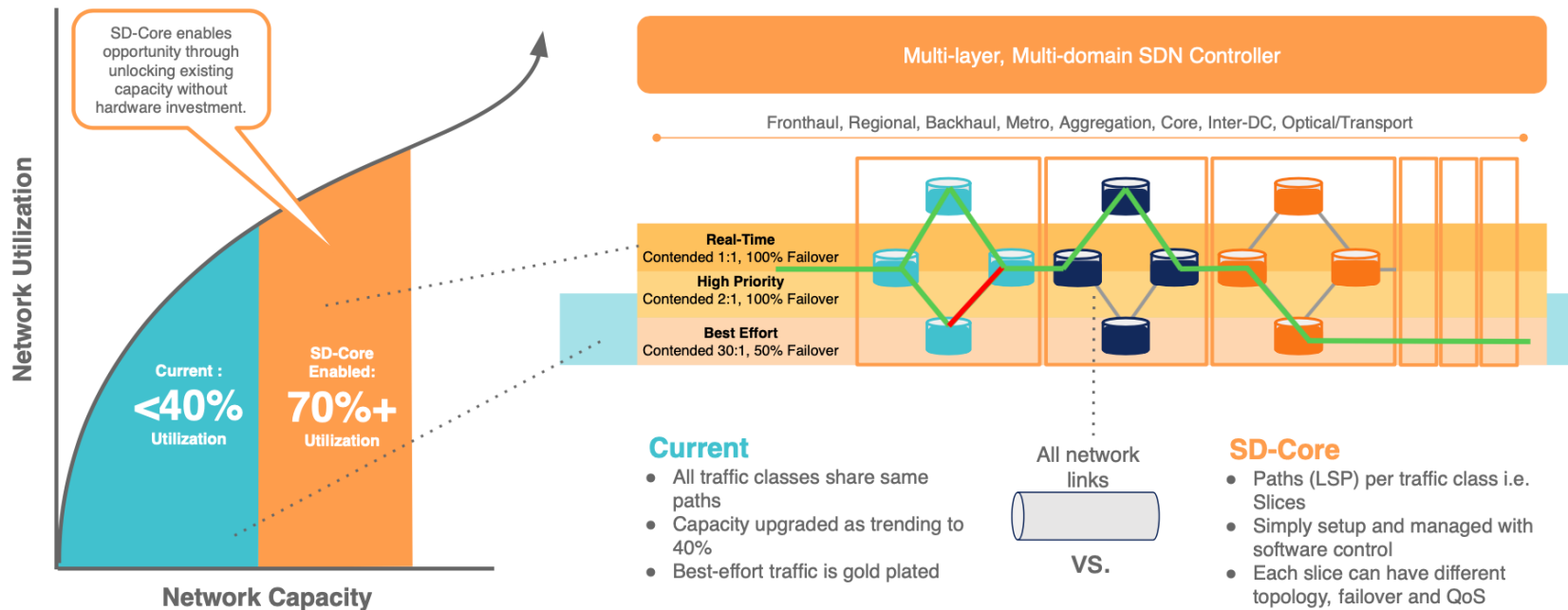
By its nature, SD-Core is not limited by use case. While addressing the issues previously considered prohibitive due to management overhead and risk (L3VPN with MPLS networks, building services across network layers and domains, etc), there are several innovative use cases linked with additional revenue streams for the SPs:



1. Improved Network Utilization

Conventional network control solutions result in 40% network utilization on an average. With lack of fine-grained traffic grooming capabilities, best-effort traffic is treated the same as real-time traffic on most network paths. This static, gold-plated model requires a lot of latent capacity to support failover concerns and does not allow for dynamic, condition-based control of network traffic - the result is poor average utilization. With a centralized SD-Core, SPs take the same physical network and topologies, and configure multiple LSP paths across the core so each traffic type can be

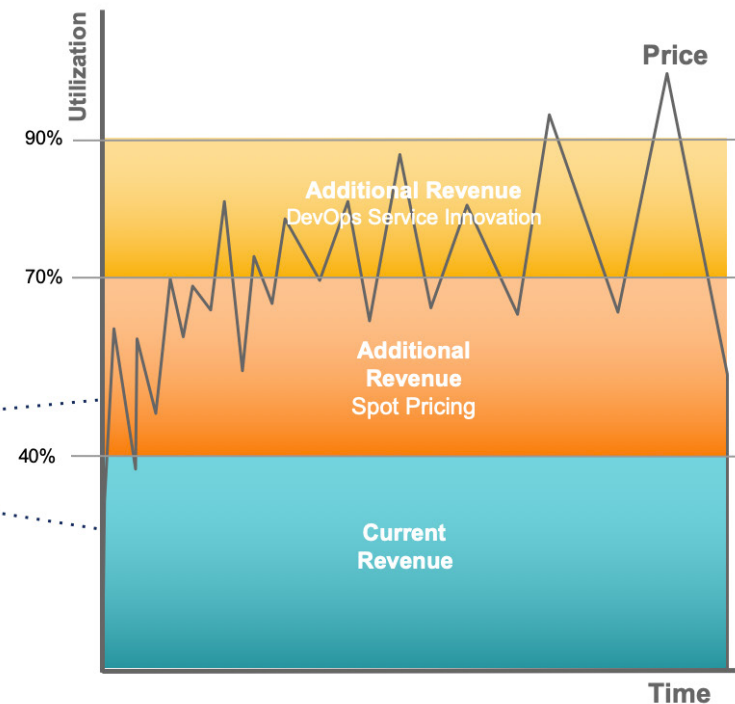
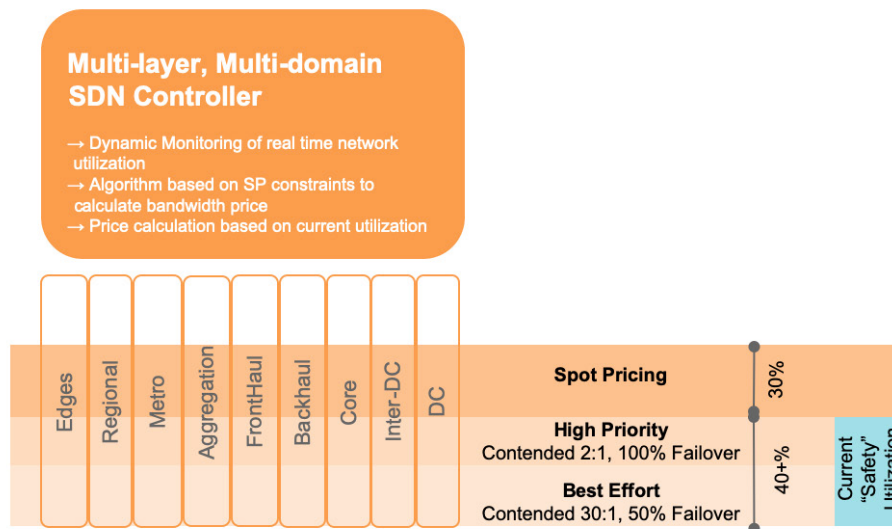
allocated to a dedicated path. These network slices can all have different topology, failover and Quality of Service (QoS), and because they are managed dynamically, they will also free latent capacity to be leveraged for new services or sold as Infrastructure as a Service. SD-Core also enables elimination of redundant paths across multiple layers (E.g. redundancies built in both optical and packet layers), thereby contributing to improved utilization.



2. Spot-Pricing Services

SD-Core also allows SPs to sell back excess capacity with dynamic, demand-based pricing. This capability follows Cloud Service Providers' lead with their consumption-based model to centralize underutilized resources and monetize on additional resources as a service. This use case allows SP customers to select services to only run once the bandwidth cost drops below a certain threshold — helping reduce network pressure at high demand times, while also supporting a more dynamic customer relationship.

With SD-Core, SPs can deliver on-demand, customizable experiences to their customers while reducing effort to operate and troubleshoot networks. By changing the way service providers manage their networks, create services, and deliver new business models, SD-Core solutions are delivering valuable results in production around the world.



MPLS Problems Solved

As networks continue to evolve, especially in the 5G space, the focus often tends to be on new network elements (radio, NFV, whiteboxes, briteboxes, etc). That said, as noted in the section above, capitalizing on traditional MPLS networks will continue to be a priority. MPLS networks (IGP + LDP + RSVP-TE) present many challenges when it comes to just keeping up with the incessant growth in traffic, the continued need to become more efficient, and ability to define new innovative complex services:

- Non-deterministic — Little or no control over the path
- Existing router hardware limitations — Cannot scale well for RSVP-TE/LDP protocols
- No single arbiter of path information — Leads to split-brain issues
- Complex mechanisms to log path cycles — No means to do historical / what-if analysis
- Complex to configure, does not scale, difficult to troubleshoot — Error prone operations
- Vendor interoperability challenges — Long cycles to deployment and troubleshooting
- No support from britebox / open source controllers

SD-Core solves the above concerns by seamlessly transitioning the MPLS network from a distributed control model to a centralized control model. It does this using standards-based protocols and working with standard network platforms available from typical vendors. It fulfills the need for an external controller (PCE) to compute paths and monitor the state of MPLS networks; providing the ability to introduce multiple constraints easily in the external

PCE, and most importantly, provide a common platform to incorporate telemetry from non-network/topology sources to make the network more intelligent and automated.

One way SD-Core simplifies MPLS networks is by leveraging Segment Routing technology. With the use of Segment Routing, the number of protocols needed to support MPLS networks is reduced and overheads associated with maintaining path-state are bypassed. These mechanisms lend themselves well to extensibility and external programmability as they are easy to understand and program. Segment routing enables source routing-based services. IGPs (Interior Gateway Protocols) distribute labels with Link State, thereby removing LDP/RSVP requirements. Segment Routing also provides the ability to work with existing core routing domains via the use of mapping services as well as introducing functionality that increases core path survivability with features such as anycast and proxy-forwarding SIDs.



Optical Network Problems Solved

Typically, optical networks are a very closed, single-vendor ecosystem. Traditional optical networks are often split across an OTN layer and a WDM layer. When it comes to disaggregated control, optical networks present several challenges:

- Closed ecosystem resulting in single vendor solutions leading to vendor lock-in
- Typically configured using proprietary EMS systems from the optical switch vendor
- Leads to bloat of software layer with different EMS systems
- Cannot mix and match vendor components (i.e. transponder from one vendor, ADM from another vendor, etc.)
- No open standards, difficult to integrate domains

The concept of opening up optical networks to disaggregated control is relatively new to the industry. SD-Core eases this transition by decoupling the single-vendor model from this layer of the network. The obvious benefit from transforming to a multi-vendor approach is the introduction of more innovation and operational control to SPs. Lumina's SD-Core does this in a few ways.

First, by following open APIs derived from standards such as ONF-TAPI, OpenROADM and IETF. SD-Core configures optical services in a vendor-neutral way, breaking down vendor lock-in. Additionally, the solution links multi-layer events to provide continuity in network intelligence and centralizes PCE to deduce paths and provision configuration for lambda switching. Eliminating multiple disparate optical EMS systems, SD-Core brings uniform configuration architecture across packet and optical domains using open APIs and standard interfaces. Lastly, the solution reduces overall software footprint for optical provisioning, further simplifying the complexities of transforming networks.

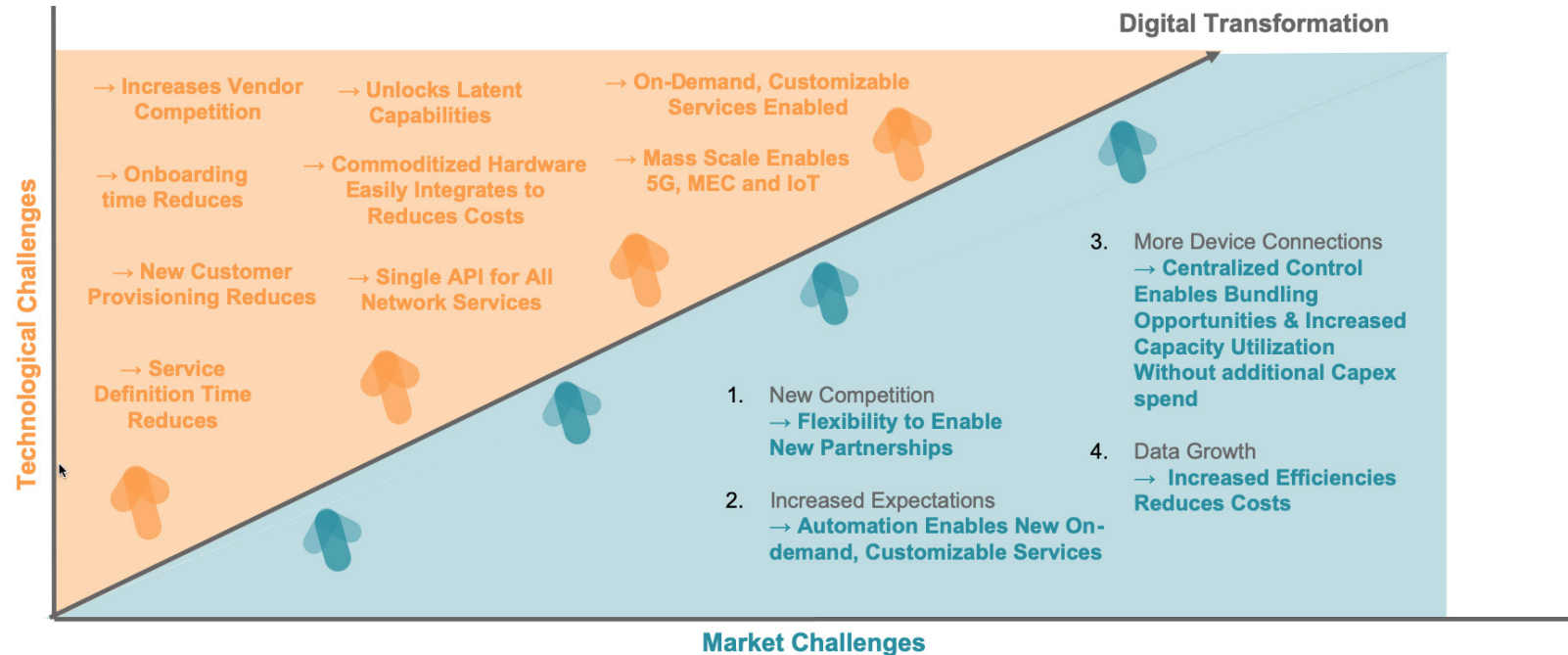


The Value of Heterogeneous Control

Ubiquitous network control is the keystone to an effective digital transformation. Without it, SPs will struggle to assume full benefit of a digital transformation as it provides the automation, flexibility and programmability needed to compete in a dynamic market place. With end-to-end control, SPs have been leveraging SD-Core to solve the challenges noted in the sections above, enabling:

- Increasing network efficiencies and reducing operating costs
- Bundling services and increasing capacity utilization without additional CAPEX spend
- Enabling new partnerships, stunting potential competitive threats
- Exceeding customer expectations by creating on-demand, customizable experiences

SD-Core provides a uniform API for an end-to-end network. With a domain agnostic PCE, SD-Core has the capability to operate on multiple topologies. The resultant functionality with its rich set of northbound APIs enables the end-to-end network visibility and control needed to provide the benefits mentioned above for all the different traffic types, at the scale anticipated for a next generation network.



Why SD-Core Requires Open Source

Open source software is one of the key pillars of transformation for the SPs. It enables innovation through collaborative community led projects, extending capabilities: functionality, integration, automation and extensibility of platforms and applications that underpin a SP's business today and in the future.

This innovation, free of vendor lock-in and vendor innovation dependencies, is the driving force behind new services for SPs which seek to consolidate existing and capture emerging market opportunities. In addition, SPs have realized other benefits including greater CAPEX/OPEX optimization across the business, with more standards to cohesively unify network vendors and domains which have historically been proprietary and siloed. By requiring vendor alignment to these standards, SPs are building the flexible foundations they need to compete and differentiate in an ever-evolving market.

OpenDaylight, a modular open SDN controller platform for customizing and automating networks of any size and scale, is one of the key open source projects and is pivotal in achieving these goals. As a control plane function, it has significant impact, delivering cohesive and comprehensive control and automation across the entirety of the network across multiple layers, domains and vendors. OpenDaylight is the most widely deployed open source SDN controller platform and in just 6 years, OpenDaylight boasts 10 releases, 1000+ authors/submitters, 100K+ commits, and powers networks of 1B+ global subscribers.

As a key community leader within OpenDaylight, Lumina Networks is focused on ensuring that ODL continues to evolve and grow with a commitment to upstreaming much of its innovation and development. With the increasing adoption of ODL it is critical that SPs leverage the innovation this brings but paramount is the supportability and availability of the platform, coupled with ease of adoption. Other key factors of importance with even greater focus are security, performance

and scale. As the ODL footprint expands and diversifies, taking ever more control of increasing devices, customers and services Lumina is dedicated to ensuring the development of ODL meets these challenges and opportunities.

To date we support some of the largest scale of deployments in the market globally and continue to invest in our vision. Lumina is to be the #1 solutions provider of ODL empowered solutions, providing SPs with a carrier-grade solution they can depend upon as a foundation for their business growth and operational excellence.



A Path to Accelerate the Transformation Journey

The open source culture is pervasive throughout the communications industry. Many SPs have dove into the open source deep end of their digital transformations with Do-It-Yourself networks. This head-first mentality comes with many challenges for companies that are still learning to understand the open source and digital worlds. For a small point solution for a very specific and low scale project, DIY may be a great way to go and learn. If, however, you're working on a foundational project like SD-Core, it's important to partner with experienced companies from which you can draw on learnings and expertise to help inspire and implement solutions while training you to succeed in the space.

Lumina's SD-Core gives you a customizable, open solution, without the DIY. Lumina's SDN Controller, based on OpenDaylight, delivers an Open source, unforked SDN Controller that scales from the smallest to the largest networks in the world. A partner with years of proven development experience delivering SDN Control in the most complex networks, Lumina delivers. Open Source OpenDaylight wrapped with features and benefits.



1. Pure-Play, Unforked Distribution

2. Hardened for Ease of Deployment & Usability - Increased Test Coverage (compatibility, scale) +30%, simple, automatable installer, curated components packaging (rpm, deb)

3. Secure - ongoing vulnerability scans and patches

4. Carrier-grade Operational Supportability - Unified control of legacy and standards-based resources, accelerated bug fix cadence & hot fixes, open source leadership, software expertise, experience from multiple Tier-1 transformations

5. Scalability - Largest scaled production deployments in the market - 10s of 1000s of nodes per cluster and increasing with forthcoming horizontal scale tech

6. Extensibility - Simple development framework in any language, dev kits & user guides

7. Added Intelligence - Ready-to-deploy carrier-grade applications driven by app/business logic, end-to-end real-time telemetry

Use Cases for Hardened, Scalable SD-Core

With end-to-end network control, Service Providers will have the flexibility they need to implement any number of use cases. The Lumina SD-Core was built with the extensibility and scalability needed to support the use cases of today and tomorrow. With that said, there are a few common use cases we have already successfully deployed which help demonstrate the powerful capability of this architecture.

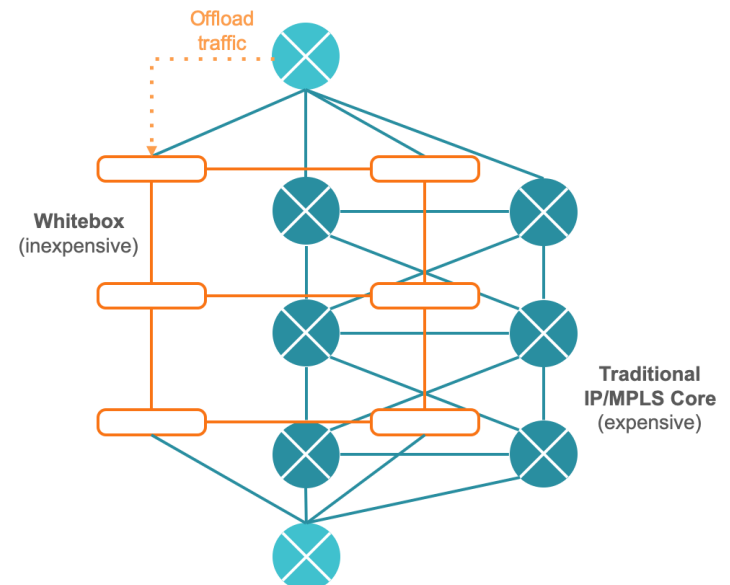
1. Greenfield Deployments

Lumina supports many use cases for greenfield deployments including datacenter interconnects and regional ethernet EOL replacements. The most commonly requested use case however, is Core Offload.

Core Offload - IP Core networks are growing at 40%+ a year, which under current network architectures means SPs have to invest huge amounts of CapEx to keep up with the increasing market demands. Core network technologies are still relatively expensive even with very high discounts due to limited competition; vendor lock-in makes it difficult for SPs to switch vendors. Fortunately, as noted above, whitebox SDN has evolved to be able to deliver the same critical WAN telco capabilities for Core, Aggregation, Backhaul and Metro/Regional networks with key SP features added. SD-Core enables SPs to deploy network in parallel to offload specific traffic types from the traditional Core to the new Whitebox SDN Core (typically starting with low-priority traffic that is getting a free ride on the gold-plated core). This approach allows for evolution of engineering, operations and IT teams to new ways of working.

Outcome from Core Offload

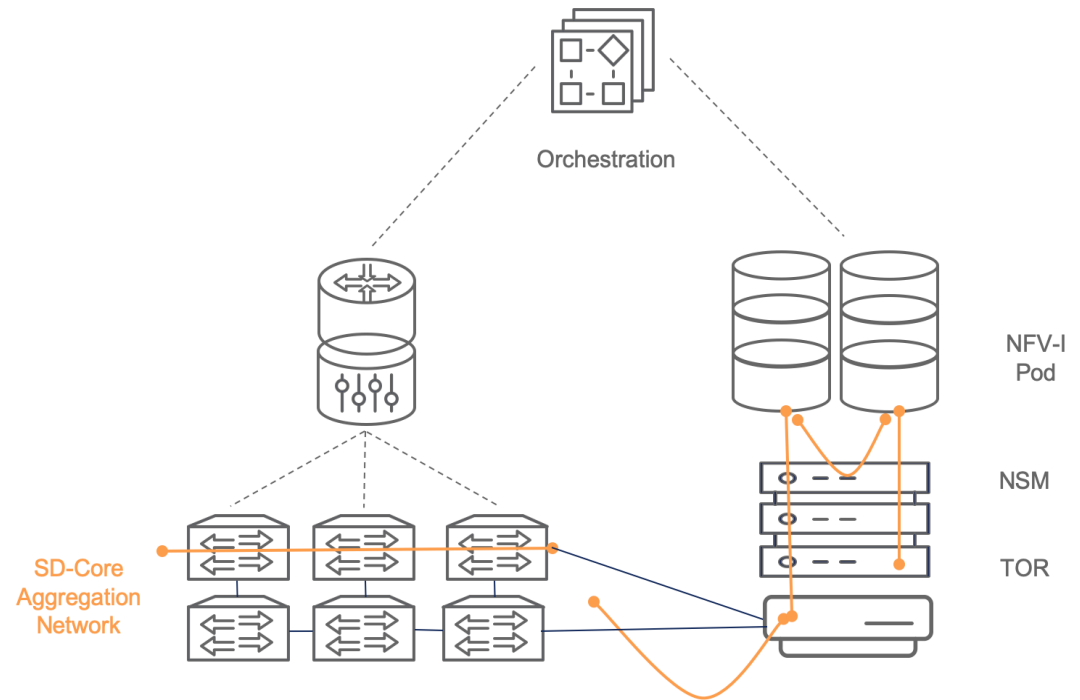
- Whitebox and SDN Controller integrated with key SP features:
 - > MPLS/SR Data Plane for scale
 - > MPLS services for transparency and backwards compatibility
 - > Segment Routing for efficient label allocation and switch forwarding tables
 - > High availability with controller clustering/reconciliation, precomputed paths and BFD for fast failure detection
- Whitebox and SDN provides lower cost infrastructure for low value/price services
- Single API for whole network with real-time provisioning and telemetry for all services



2. Brownfield Deployments

Painfully clear by now, supporting the transformation of physical legacy resources is an important area of focus for SD-Core. Use case deployments including edge compute networking, service-aware core, 5G network slicing, bandwidth calendaring, OTN/WDM control. The most commonly requested use case however, is Edge Compute Networking.

Edge Compute Networking - SPs are looking to deploy small / micro data centers distributed at the edge of their IP networks at the access. Distributed data centers require networking from the CNF/VNF through the DC TOR and across the WAN into the overarching service. These network services need to be as dynamic as the CNF/VNF service orchestration. While typically there is a good dynamism available for the virtual infrastructure, the same flexibility doesn't extend to the remaining parts of the networks spanning from the edge to across the WAN and to the user. As a result, edge compute services still suffer from the weak link - the lack of dynamic network control at the WAN. SD-Core enables telcos to offer consumption based CNF/VNF value-added services, on top of their core VPN business, by dynamically controlling all parts of the network connecting the application infrastructure to the user. Lumina is a proud member of the Network Service Mesh open source project that unifies WAN and Edge automation while maintaining a VIM/network vendor agnostic approach with container support for microservice applications.



Outcome from Edge Compute Networking

- Edge compute workloads can now be orchestrated with the WAN to avoid overlays or long lead times to provision
- 5G, on-demand and customizable service delivery is enabled with intelligent edge resources
- Improved resource efficiencies while optimizing user experience

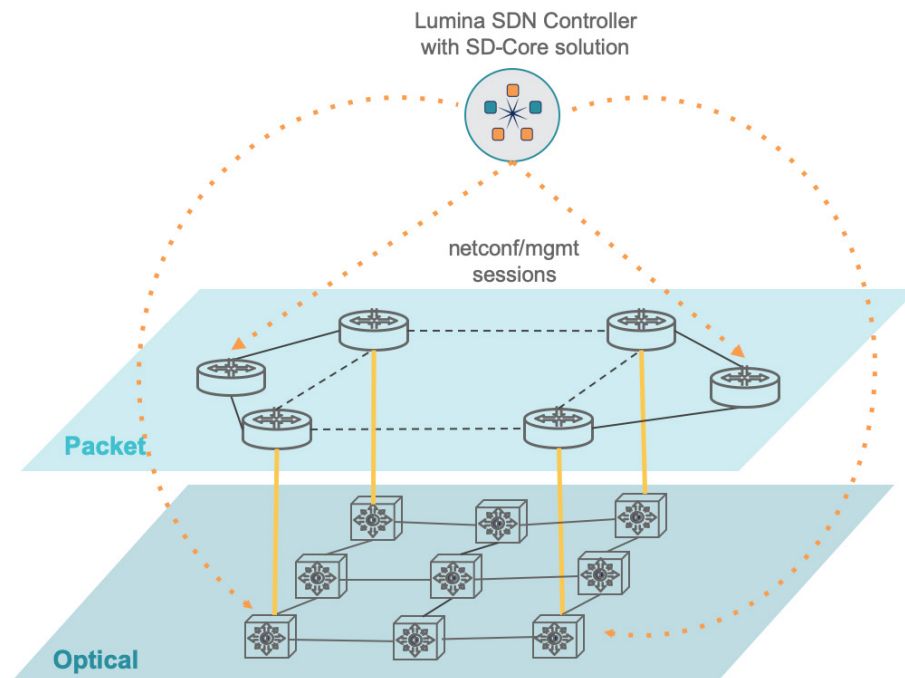
3. Multi-Domain, Multi-Layer Deployments

Because of SD-Core's ability to control any network element in any domain, one of the most common use cases for SD-Core is cross layer — Optical, Packet, and beyond. This use case includes multi-layer visibility and correlation, but almost always starts with multi-domain requirements.

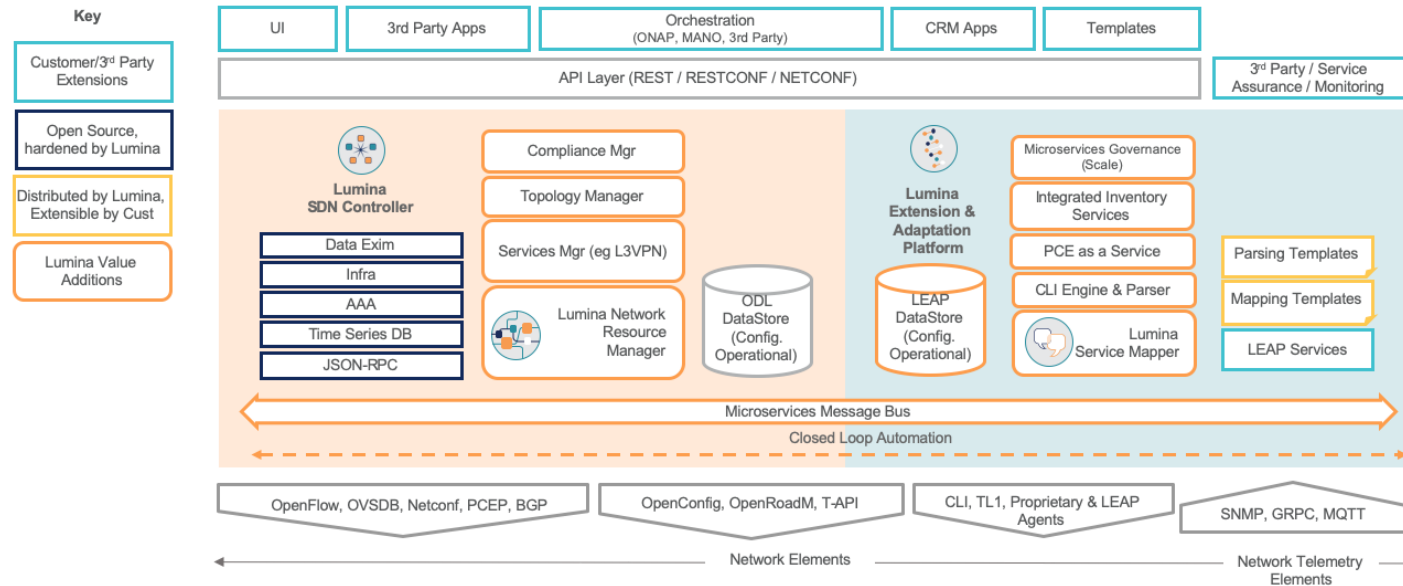
Multi-Domain/Multi-Layer Networking - To enable network slicing and end-to-end automation, Service Providers need to be able to work across multiple domains. Leveraging disparate network resources as a single unit across any layer and any box is the corner-stone for nearly every digital transformation strategy we've seen. In this case SD-Core is used to unify end-to-end traffic grooming and inter-domain traffic engineering. The solution connects any domain (MPLS, OpenFlow, P4) to a single platform which can then be programmed and automated as a single unit. Multi-Layer is a further specialized case under multi-domain networking, wherein the solution can further perform cross-layer correlation and react to failures across layers in a policy-driven way, thereby effectively implementing Multi-Layer-Restoration.

Outcome from Multi-Domain/Multi-Layer Networking

- Services stitch together across heterogeneous domains with a single multi-domain software API
- Functions like network slicing and application placement are enabled end-to-end
- Manual processes are curtailed and devops practices enabled with a flexible foundation for innovation creation.
- Cross-layer correlation for failures
- Policy-driven restoration
- Effective network utilization by removing unwanted redundancies that are built in multiple layers



Lumina SD-Core Products



The Lumina SD-Core solution has several product components which create the above mentioned capabilities:



- **Lumina SDN Controller** - The Lumina SDN Controller powered by OpenDaylight (ODL) provides a common, open platform for service providers or developers, giving direct control over SDN development and implementation. This emerging approach helps eliminate vendor lock-in and puts users in charge of their own network evolution. The Lumina SDN Controller is a quality-assured edition of the industry-leading OpenDaylight controller. Combined with Lumina's NetDev Services, providers can implement software-defined networks on their own timeline using an Agile development methodology.

At a high-level, the OpenDaylight controller has three parts:

1. A central model-driven service abstraction layer that normalizes all data exchange via YANG
2. A "southbound" selection of control interfaces that connect to common switches and routers using protocols such as NETCONF, OpenFlow, BGP/PCEP and OVSDB.
3. A "northbound" API aimed at supporting applications using RESTCONF. This architecture allows the controller to enable software-defined networking by abstracting and normalizing the interface to a variety of network devices and providing telemetry for closed-loop automation.



- **Lumina Network Resource Manager** - This suite of applications enable better utilization of the network by intelligently managing slices, creating paths through these slices and mapping services to the paths. Through these actions, the telco is now enabled to control costs on the network, as well as better groom traffic to guarantee appropriate treatment. In addition, the telco is also empowered to start offering services for 5G. The three variations of this application — LNRN-Packet, LNRN-Optical, LNRN-Flow — are adapted to make sure end-to-end control is supported.

To enable other use cases including closed-loop automation and real-time telemetry, these Lumina products help create and end-to-end solution:



- **Lumina Extension & Adaptation Platform** - LEAP is a modern software framework from Lumina that enables automation of legacy network elements using model-driven frameworks, in an extensible fashion. LEAP extends Lumina's OpenDayLight based SDN controller using a microservices architecture and enables better integration with business layers. LEAP also promotes the addition of new microservices based components in a language-agnostic manner, thereby enabling operators to use the Python skills of their DevOps teams to extend their service automation frameworks in-house, based on business demands, without dependency on external vendors. In addition, LEAP facilitates a rich monitoring infrastructure with diverse southbound plugins including gRPC & gNMI and traditional SNMP interfaces, to enable device telemetry collection for network visibility.



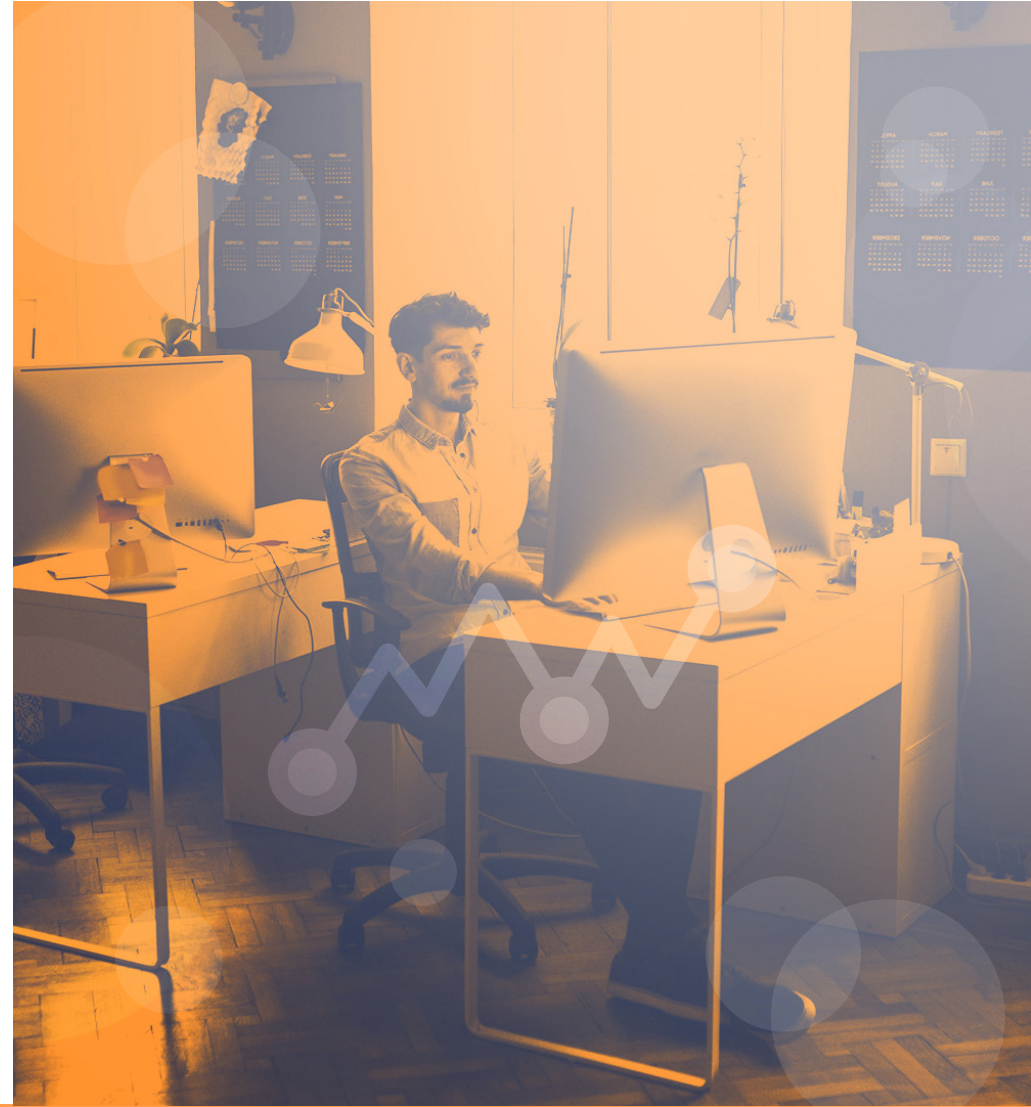
- **Lumina Service Mapper** - With the advent of SDN interfaces like netconf, most OEMs have started supporting netconf interfaces natively in the Network Elements. However, the YANG models exposed by the NEs are still proprietary, and every OEM ends up projecting YANG models that are a reflection of their CLIs, or a proprietary model. As a result, operators are still left with having to deal with a multitude of models for the same service. Lumina Service Mapper is an intelligent application that enables seamless model translation from standardized data models to vendor proprietary models. Working in unison with the Lumina SDN Controller, the application translates models for proper network configuration by the controller. LSM also enables normalization of alarms in the monitoring path, enabling vendor-neutral alarm collection and monitoring. LSM greatly simplifies operators quest in true end-to-end service automation and monitoring, using its extensible translation framework.





Lumina's team of NetDev Services expert can help effectively implementation of the SD-core solution. With years of open source leadership, hundreds of fixes and lines of code committed, and several successful tier-1 production deployments, our services team has the experience and training needed to help guide your transformation.

Our worldwide team of open source networking experts work in agile sprints to design and deploy customized solutions to fulfill your specific business needs. This development exercise, managed in conjunction with our customers, helps transforming teams reach technical and operational objectives. NetDev customers have successfully implemented and co-developed solutions to enable agile, automated mobile and fixed telecommunications networks around the world. By working alongside our team of open source leaders, some of the world's most advanced Service Providers have learned to thrive in this dynamic marketplace while accelerating their transformation processes. Together, we changed service deployment processes, simplified service creation and support, and created unified multi-vendor network control.



About Lumina Networks

We take supported OpenDaylight projects, vetted by the community, for safe and secure deployment into the network. Our own NetDev team works directly with internal development teams to build the tools specific to an organization which ensures secure and reliable implementation.

We believe in teaching our customers "how to fish," sharing our best practices and offering our expertise along the way. Companies quickly expand the skills and abilities of their development teams while removing the reliance of outside consultants where vendors lock in to use their product. Lumina Networks and its SD-Core platform can be deployed across a wide spectrum of business verticals without hesitation. Additionally, our NetDev services combined with close relationships with the Linux Foundation means companies always have the newest and most innovative solutions available to solve critical business problems.

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