TOMORROW starts here.
Multi-Layer Network Architectures

BRKOPT-2118

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Agenda

• Intro Multi-Layer Architecture
• Classic Multi-Layer Network Components
  – IP/MPLS
  – OTN
  – Photonic Layer
  – Control Plane
• Converged Multi-Layer Network Architecture
• Summary
Abstract

Abstract: This session will explore the role of IP/MPLS, OTN and DWDM when used as individual, independent network layers in Service Provider or Large Enterprises, their main applications and highlight the strengths of each one. It will then introduce the concept of a Multi-Layer Architectures and how they allow tighter integration from a hardware, software and control plane point of to improve the overall network efficiency. The role of the network layers will be revisited in the context of the Multi-Layer Architecture. The session will end with an overview of market trends and evolution and how these architectures will be key to address the exponential bandwidth growth challenge faced by the industry in the next several years.
Introduction
The Challenge

Near-Term Constraints

Long-Term Vision
Today’s Service Provider Challenges
Strong Growth in Many Different Facets Pressures Profitability

- **13x** increase in mobile data traffic over four years
- **66% CAGR** for Mobile Data Traffic
- **Cloud Traffic** to grow 6X and reach **4.3 Zettabytes** by 2016
- **2012** created more information than the past **5000 years** combined
- **700 Days of Constant Video** will traverse internet every second
- **1/3 of data** will go through the cloud in 2017
- **50 Billion Connected Things** by 2020
- **M2M Devices Growing 5X Faster than Mobile Devices**
- **Mobile Devices Growing 4X Faster Than Human Population**
- **More than 50% of web connections** will be mobile by 2013
- **More than 22% of all networked events** will be M2M based by 2017

Sources: The Economist, Cisco Visual Networking Index (VNI) Global Data Traffic Forecast, 2012–2017, Machina
The World of SP Networking is Changing

Next Step in Evolving SP Networks
Simple, Fast, Virtual, Efficient

- Embrace SDN and Network Virtualization
- Centralized Control for Network Optimization
- Dynamic Cloud Based Service Delivery over MPLS Networks
- Programmatic Interfaces and Orchestration

Addressing Pain Points through Rapid Evolution – Not Revolution

- Convergence of IP/MPLS and Optical Transport
- Operates with existing hardware platforms
- Simplified control plane – more scalable data plane
- Centralized control for Admission Control and Policy Engine for network optimization and dynamic service placement
Evolved Programmable Network Architecture
Addressing Today’s and Tomorrow’s Challenges
Multi-layer Network Architecture Proposals

• Break network silos.

• Leverage latest industry technology developments:
  – Multi-layer control plane.
  – Multi-layer network planning tools.
  – SDN Controllers with global network view.
  – Converged network platforms.
  – Dynamic transport layer.

• Each network layer can participate in the multi-layer architecture while still provides traditional services.
Cisco nLight Technology for ML networks

Programmability, Convergence, and Scale

nLight Silicon
100G+ Coherent Adaptive Rate High Performance

nLight Control Plane
Information Sharing The Network is the Database Automation to Optimization

nLight ROADM
Complete Flexibility No Manual Intervention Massive Scale
Cisco’s Open ML Architecture

- **Foundation of Cisco Architecture: Transport Layer**
  - Open DWDM architecture support Black Link ITU G.698.2 for 2.5 and 10G
  - Process of working with Multi vendor and SPs to extend to 40Gig and 100Gig
  - Multi Vendor DWDM OEO interop
    - Supporting PMO or IPoDWDM with or Without Regen

- **Introduction of nLight ML Control Plane Architecture**
  - Based on IETF GMPLS-UNI implementation as defined in RFCs
  - Architecture to support not only IP and Optical but also OTN truly multi Layer
  - Respect Operational Boundaries yet support intelligent Sharing of information
  - Laying the path for vendor agnostic SDN
  - Upto 60% interface savings can be achieved!!
Enabling SDN

• Multi-Layer Applications
  – Visualization
  – Design and Optimization
  – Provisioning and Assurance
• Multi Layer Global View and API
• Dynamic ML Control Plane
• Dynamic Packet Layer
• Dynamic Optical Control Plane
• Dynamic DWDM Foundation
A Phased Approach to SDN

nLight Multi-Layer Control Plane
Multi-Layer Information Sharing and Provisioning
Leverage GMPLS-UNI

Network Optimization
Powerful offline analysis of real-time data
Cisco Quantum WAN Orchestration – Cisco MATE

Dynamic Online Multi-Layer Control
Dynamic Online Multi-Layer Capabilities
Hybrid Control - best of distributed and centralized
Technology Trends
Packet, OTN, Photonic Layer
IP/MPLS Observations

• IP/MPLS is a ubiquitous Forwarding Plane for L2 and L3 Services
  – VPWS, VPLS, L3VPN, RFC3107 Hierarchical LSPs

• Reliability, Scalability and Simplicity greatly improved
  – LFA FRR
  – BGP PIC Core/Edge
  – TE Auto-Tunnel Mesh/Backup

• MPLS is becoming more “Transport like” via FlexLSP (bi-directional TE Tunnels)

• L2 Service Redundancy greatly improved
  – Hot-Standby PW Redundancy
  – Multi-Chassis LAG/LACP
  – L2 TCN – PW MAC Withdrawl Interworking
## Comparing Technologies – MPLS-TP

<table>
<thead>
<tr>
<th></th>
<th>IP/MPLS</th>
<th>MPLS-TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Capability</td>
<td>E-Line, E-LAN, L3 VPN</td>
<td>E-Line</td>
</tr>
<tr>
<td>Network Management</td>
<td>FCAPs</td>
<td>FCAPs</td>
</tr>
<tr>
<td>Edge Functionality</td>
<td>Extensive edge processing</td>
<td>Extensive edge processing</td>
</tr>
<tr>
<td>Functionality required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Plane</td>
<td>MPLS</td>
<td>MPLS</td>
</tr>
<tr>
<td>Control Plane</td>
<td>IP/MPLS</td>
<td>NMS</td>
</tr>
<tr>
<td>LSP config / Mgmt</td>
<td>Signalled (LDP/BGP or MPLS-TE)</td>
<td>Static</td>
</tr>
<tr>
<td>Protection</td>
<td>Primarily Control Plane driven</td>
<td>OAM driven</td>
</tr>
<tr>
<td>OAM</td>
<td>Basic, but MPLS-TP OAM applicable</td>
<td>Extensive</td>
</tr>
<tr>
<td>LSP</td>
<td>Unidirectional</td>
<td>Co-routed Bi-directional LSPs</td>
</tr>
</tbody>
</table>
Flex-LSP
Co-routed Associated Bidirectional LSP

- R1 acting as master and request red tunnel towards R2
- Upon completion R2 request blue tunnel in the exact reverse path
- OAM - Extensive using GAL/GACH – Probe and event
- Completely compatible to with native MPLS services
<table>
<thead>
<tr>
<th>Capability</th>
<th>MPLS-TP</th>
<th>Flex-LSP</th>
<th>LDP/BGP</th>
<th>MPLS-TE</th>
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</thead>
<tbody>
<tr>
<td>Protocol Support</td>
<td>VPWS</td>
<td>VPWS / VPLS / L3</td>
<td>VPWS / VPLS / L3</td>
<td>VPWS / VPLS / L3</td>
</tr>
<tr>
<td>Data Plane</td>
<td>MPLS</td>
<td>MPLS</td>
<td>MPLS</td>
<td>MPLS</td>
</tr>
<tr>
<td>L2 Construct</td>
<td>Pseudo-wires</td>
<td>Pseudo-wires</td>
<td>Pseudo-wires</td>
<td>Pseudo-wires</td>
</tr>
<tr>
<td>Control Plane</td>
<td>None : NMS / G-MPLS</td>
<td>RSVP-TE</td>
<td>IP/MPLS (LDP)</td>
<td>IP/MPLS – RSVP-TE</td>
</tr>
<tr>
<td>LSP config / Mgmt</td>
<td>Static / G-MPLS</td>
<td>Signalled – RSVP-TE</td>
<td>Signalled – LDP/BGP</td>
<td>Signalled – RSVP-TE</td>
</tr>
<tr>
<td>Bidirectional LSP</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Co-routed</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes – ERO based</td>
</tr>
<tr>
<td>Midpoint associated</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Predictable Path</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes – ERO based</td>
</tr>
<tr>
<td>Diverse routed LSPs</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>LSP merge</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>PHP</td>
<td>No</td>
<td>No</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>Guaranteed QoS</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>LSP protection</td>
<td>OAM driven protection</td>
<td>1. OAM driven CP – IP LFA</td>
<td>2. MPLS-FRR CP - MPLS-FRR</td>
<td></td>
</tr>
<tr>
<td>Pseudo-wire OAM</td>
<td>Yes (ACH based)</td>
<td>Yes (ACH based)</td>
<td>Yes (ACH based)</td>
<td>Yes (ACH based)</td>
</tr>
<tr>
<td>LSP OAM</td>
<td>Extensive using GAL/GACH – Probe and event</td>
<td>Extensive using GAL/GACH – Probe and event</td>
<td>Basic probe based</td>
<td>Probe based</td>
</tr>
</tbody>
</table>
Simplification – Evolve Unified MPLS

Today

- Unified MPLS
  - Data plane: MPLS
  - Domain CP: IGPv4 + LDP
  - Inter-domain CP: BGPv4 with labels
  - VPN: MP-BGP and tLDP signaling
  - VPN data plane: Label in MPLS

Future

- Unified MPLS with SR
  - Data plane: MPLS
  - Domain CP: IGPv4/v6 + SR
  - Inter-domain CP: Controller based
  - VPN: Static, MP-BGP and tLDP signaling
  - VPN data plane: Label in MPLS

- Close existing gaps in Unified MPLS (multicast, timing etc)
- Protocol simplification – SR and SDN concepts
- Configuration simplification – autonomic networks / zero touch provisioning
- Service configuration and linkage – FSOL VPNs / SDN driven service activation / SDN driven n/w adjustment
Segment Routing

• IP/MPLS architecture that seeks the right balance between distributed intelligence and centralized optimization and programming. It seeks to simplify the operation of MPLS (lower opex), to enable application-based service creation (new revenue/better service) and allow for better utilization of the installed infrastructure (lower capex).

• An IP/MPLS architecture with wide application - OTT, SP, Large Enterprises - WAN and DC.

• Despite its VPN success, MPLS has little success in terms of service assurance (FRR node protection is deployed in less than 10% of the market), TE is deployed in less than 5% of the market. Any SDN transition base on MPLS classic would be confronted with strong push-back due to complexity tax of LDP/RSVP-TE FRR and Traffic Engineering base solutions. OTT providers were the rare ones operating MPLS TE capabilities and publicly quoted that better solution were required in terms of optimality and predictability, hence moving towards SDN based centralized solution. SR fits that transition.
Balance of Distribution and Centralization

Segment Routing
Distribution: Simple, Prefix Segments, TILFA
Centralization: Swift & optimum Tactical TE

RSVP-TE
Non-optimum, non-predictable, and experienced as too complex

OpenFlow
Scalability? Deployability within 18 months?
Segment Routing

• Source Routing: the source chooses a path and encodes it in the packet header as an ordered list of segments.

• Segment: an identifier for any type of instruction
  – Service
  – Context
  – Locator
  – IGP-based forwarding construct
  – BGP-based forwarding construct
  – Local value or Global Index

Segment = Instructions such as "go to node N using path Y"
Simplification – Segment Routing

- Application Enabled Forwarding
  - Each engineered application flow is mapped on a path
  - A path is expressed as an ordered list of segments
  - The network maintains segments

- Simple: less Protocols, less Protocol interaction, less state
  - No requirement for RSVP, LDP

- Scale: less Label Databases, less TE LSP
  - Leverage MPLS services & hardware

- Forwarding based on Labels with simple ISIS/OSPF extension

- 50msec FRR service level guarantees

- Leverage multi-services properties of MPLS

The state is no longer in the network but in the packet
Simplification – Segment Routing

Forwarding state (segment) is established by IGP
   ➢ LDP and RSVP-TE are not required

MPLS Dataplane is leveraged without any modification
push, swap and pop: all what we need
segment = label

Nodal segment: Operator allocates a
label from the SR registry to each node.
For example Z is given label 65

Adjacency segment: Node automatically
allocates a local label for each adjacency.
For example Label 9001 allocated for
adjacency O

A packet injected anywhere
with top label 65 will reach Z

A packet injected at node C
with label 9001 is forced
through datalink CO
Combining Segments

- **ECMP**
  - Node segment

- **Per-flow state only at head-end**
  - not at midpoints

- **Source Routing**
  - the path state is in the packet header
Segment Routing

- Provides path end traffic engineered path selection
- Done only at one node at the headed. No hop by hop data plane programming
- No RSVP
- No LDP. Labels distributed in ISIS
- No state in the network. Simpler control plane
- Application oriented
IP/MPLS Importance

• Converged IP transport architecture
• Provides the data plane for any type of packet services
  – MEF compliant: E-LINE, E-LAN, E-TREE
• Transport like data plane using FlexLSP in lieu of MPLS-TP
• Traffic engineering and protection
  – LFA / MPLS-TE FRR
  – Segment routing
• Common signaling protocol with the OTN and DWDM layer - GMPLS
Optical Transport Network (OTN)

• Standards :
  – G.709 → Hierarchy and frame structures
  – G.872 → Architecture
  – G.798 → Management functions etc

• Defines G.709 as a framing technology and hierarchy that is very similar to SONET/SDH.

• G.709 started as a wrapper around WDM client signals to improve reach and manageability

• Evolved to a complex multiplexing hierarchy that enables a service layer

• Forward error correction (FEC) to improve error performance and enable longer optical spans.

G.709 Hierarchy

<table>
<thead>
<tr>
<th>Frame</th>
<th>Payload (OPU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODU0</td>
<td>1,238,954 kbit/s</td>
</tr>
<tr>
<td>OTU1</td>
<td>2,488,320 kbit/s</td>
</tr>
<tr>
<td>OTU2</td>
<td>9,995,276 kbit/s</td>
</tr>
<tr>
<td>OTU3</td>
<td>40,150,519 kbit/s</td>
</tr>
<tr>
<td>OTU4</td>
<td>104,355,975 kbit/s</td>
</tr>
</tbody>
</table>
Optical Transport Network (OTN) Model

Optical Channel (Och)

Optical Multiplex Section (OMSn)*

Optical Transmission Section (OTSn)*

OTN Options

- **Optical OTN**
  - DWDM Transport
  - All Optical Network
  - Lambda or Sub-lambda services
  - Cross-connect or switching at the Lambda/Wavelength Level

- **Electrical OTN**
  - SONET/SDH Evolution
  - Switching of ODU-k containers
  - Circuit services
  - Can use Optical OTN as transport

*Under Definition.*
G.709 Frame

Client Signal

OPUk - Optical Channel Payload Unit

ODUk - Optical Channel Data Unit

OTUk - Optical Channel Transport Unit

Alignment
OTN Frame Elements

- **OPU** – Optical channel Payload Unit:
  - Contains the client signal. *End to End* envelope. Overhead information includes payload time.

- **ODU** – Optical Channel Data Unit:
  - *Network level* management functions. Can contain multiplexed signals.

- **OTU** – Optical Channel Transport Unit:
  - Management between *network elements*.

![OTN Frame Elements Diagram](image-url)
Basic G.709 Multiplexing Hierarchy

ODUFlex – hitless bandwidth resizing;
ITU-T G.709 Mapping

**Client Payload**

**OTUk**
- **OH**
- **OPUk**
- **ODUk**
- **IP**

**FEC**

**ESCON/FC**

**Ether**

**GFP-F**

**GFP-T**

**G.Sup43**

**SONET/SDH**

**ATM**

**k** Indicates the Order:

- 0 = 1.25G (ODU Only)
- 1 = 2.5G
- 2 = 10G
- 3 = 40G
- 4 = 100G
OTN Overhead

- OTN Overhead information allows for network monitoring and management, between Network Elements (NEs) and end-to-end.
OTU Overhead

- Information for transport through optical channel connections.
- 7 columns/1 row assigned to OTUk overhead
- 3 columns for Section Monitoring (SM) contains:
  - Trail Trace Identifier (TTI)
  - Bit Interleaved Parity 8 (BIP-8)
  - Backward Defect Indication (BDI)
  - Backward Error Indication and Backward Incoming Alignment Error (BEI/BIAE)
  - Incoming Alignment Error (IAE)
- 2 columns GCC0
  - Inband communication channel as defined in ITU G.7712
Forward Error Correction (FEC) Compensates for Optical Impairments

- FEC extends reach and design flexibility, at “silicon cost”
- G.709 standard improves OSNR tolerance by 6.2 dB (at 10−15 BER)
- Offers intrinsic performance monitoring (error statistics)
- Higher gains (8.4 dB) possible by enhanced FEC (with same G.709 overhead)

**Benefit:** FEC/EFEC Extends Reach and Offers 10−15 BER
Proactive Protection

Transponder in Router

Traditional

Reactive Protection

Router Bit Errors

FEC Limit

Time

Pre-FEC Bit Errors

working route

fail over

protect route

LOF

IP-over-DWDM

Proactive Protection

Router Bit Errors

working route

protect route

Switch

Pre-FEC Bit Errors

FEC Limit

Protection Trigger

Time

ROADM

ROADM

Proactive Protection

Traditional
Importance of OTN in context of the Architecture.

- Bandwidth granularity – sub lambda multiplexing
  - Eliminate the operation pain of p-t-p muxponder
  - Allows for upper layers to have less than lambda interface
  - Grooms sub-lambda circuits to increase efficiency

- Mesh Protection switching

- Native support for legacy TDM traffic

- Rich OAM capability

- Near lossless convergence for IP with pro-active protection
Foundation EPN - Next Gen ROADM

Problem
Unrelenting Bandwidth Growth

Solution
More network capacity

More Channels
Extend the 50GHz C-Band

Flex Spectrum
Spectrum Optimization Future Proof

Problem
Dynamic traffic Tighter SLAs Inefficient Utilization

Solution
Highly meshed, programmable networks

More Degrees
More highly meshed networks

Touchless Operation
Colorless Omni-directional Programmability
IP/Optical Integration – Touchless, Agile Optical Layer

Complete Control in Software, No Physical Intervention Required

Omni-Directional – ROADM ports are not direction specific (re-route does not require fiber move)

Colorless – ROADM ports are not frequency specific (re-tuned laser does not require fiber move)

Flex Spectrum – Ability to provision the amount of spectrum allocated to wavelength(s) allowing for 400G and 1T channels.

Contention-less – Same frequency can be added/dropped from multiple ports on same device.

Tunable Transponder – Color and modulation. Ability to derive max b/w based on distance and fibre quality

Foundation for Multi-Layer Network Programmability
nLight ROADM
Flex Spectrum

- Graceful growth to terabit and greater superchannels
- Lighting the way to flexible, dynamic packet to wavelength mapping
- Optimize bandwidth vs. distance
FlexSpectrum DWDM Architecture

DSP-enabled Transmitters

FlexSpectrum ROADM

Signal Shaping

Denser Channel Spacing

Ch1  Ch2  Ch3  Ch4

Today's 50GHz and System

50GHz  50GHz  50GHz
Channel Flex

Flexible, efficient and dynamic mapping of packet services to optical transport

- **NPU**
  - Flex MAC
    - Flexible nx5G/25G interconnects

- **Transponder**
  - Flex Mod
    - 50G/100G/200G DWDM interfaces

- **DWDM**
**Flex Mod**

Transponders supports Nyquist shaping and software configurable modulation.

- 50G PM-BPSK
- 100G PM-QPSK
- 200G PM-16QAM

28 Gbaud/s Nyquist shaped
Flex MAC

Flex MAC was designed to provide the following:

- Ability to adapt the data rate of the line interface to meet the available performance of the DWDM layer
- Allow for channel rate definitions outside the stringent hierarchies defined today in the ITU and IEEE without the need of LAG (Data Rate must be within capabilities of Network Processing Unit - NPU)
- Allow for hitless reconfiguration of Service channels

```
10G/s Media Independent Inte
Physical Coding Sub Layer
Physical Coding Sub Layer (20:10 / 10:4)
CAUI – 100G/s Attachment Unit Interface (10.3G/s per Lane)
Physical Media Dependent
Media Dependent Interface

MAC
Reconciliation
CGMII
PCS
20 Virtual Lanes
PMA
10/4 Phy. Lanes
PMD
MDI
Optical Medium

Lane Scrambler

Flex MAC AM insertion
BIP insertion

Flex MAC AM insertion
BIP insertion

... 

Flex MAC AM insertion
BIP insertion

... 

Physical Lane Multiplexer
```
Optical Control Plane Evolution

nLight
Information Sharing
The Network is the Database
Automation to Optimization
Improved Network Economics

GMPLS-UNI
Multi-Layer Provisioning

WSON
Embedded Optical Intelligence
Wavelength Switched Optical Network

- **WSON** It is a GMPLS control plane which is “DWDM aware”:
  - LSPs are wavelengths
  - Control plane is aware of optical impairments
  - Enables:
    - Wavelength setup on the fly
    - Wavelength re-routing (restoration)
    - Wavelength revalidation against a failure reparation

- Lowers CAPEX and OPEX of the end-to-end solutions even further
What if we Integrate IP Control Plane with WSON?

• Optical circuit turn up time can be reduced
  – On Demand Bandwidth Provisioning via signaling

• Circuit request can be constrained to avoid risk sharing
  – SRLGs information shared via signaling

• Alarms from both layers can be correlated
  – Easier troubleshooting

• Automated signaling can be used for maintenance coordination

• End-to-end network can be optimized
  – With centralized, Multi-layer Control Plane
GMPLS UNI

BRKOPT-3010 session provides in depth information about GMPLS.
Extended GMPLS UNI

• For each circuit signaling, a client may be informed of
  – Circuit-ID – unique identifier in server context
  – SRLGs along the circuit
  – Latency through the server network
  – Optical cost for the circuit
  – Path through the server network

• A client may be informed of
  server topology/resource

• Information continuously refreshed
Extended GMPLS UNI

• When signaling a circuit, a client may request
  – server SRLG’s to be excluded or included
  – the path to follow another Circuit-ID
  – the path to be disjoint from another Circuit-ID
  – an optimization or bound on latency

• Policy Controlled by the Server Layer
Dynamic Optical Restoration
Touchless Optical Layer + Embedded WSON Intelligence

Fiber Cut!
Embedded WSON intelligence locates and verifies a new path (using different wavelength)
Edge Nodes instruct client to re-tune its wavelength
Colorless, Omni-Directional ROADM switches the path
Service is brought back up with the **same Client and Optical interfaces**, zero touches
nLight Control Plane enabled features

1. Ability to set up an L0 path from L3;
2. Share L3 path constraints with L0;
3. Report properties of L0 path to L3;
4. Change L0 path for L3 links, due to local failures or re-optimization opportunities;
5. Change the L3 topology, due to large failures or re-optimization opportunities.
The Foundation …

Key Values
- Truly intelligent Service Routing with Full Transport Awareness
- Strengthen Operational Practices
- Advanced Protection providing ZPL
- Restore lost BW to the network with no additional CAP nor OP Ex

End to End Cisco provides the following value:
- Increase Service Velocity
- Enhance Availability
- Improve Planning and Forecasting
- Decreasing TCO
nLight Control Plane

Packet Layer
Programmable and Virtualized
Massive Scale and Density – NCS 6000, ASR 9000, CRS

nLight Control Plane
GMPLS-UNI extensions – submitted to IETF
Constraint based routing - latency, SRLG, diversity
Multi-layer Restoration

Optical Layer
OTN, DWDM, and Packet Integration – NCS 4000
nLight Touchless, Programmable ROADM – NCS 2000
Control Plane Features enabled …

- The Network as the Database
  - SRLG Cost
  - Latency Path
  - Circuit ID Disjoint / Matching
  - Performance Protection

- Enhanced ML Features
  - Constraint Based Circuit Requests
  - Multi-Layer Restoration – Optical and Port
  - Multi Layer Optimization
  - Coordinated Maintenance

- Reduce Cap Ex and OpEx
  - Up to 60% few interfaces
  - Less Power
  - Less Real estate
MultiLayer Architecture
Defining IPoOTN Convergence
Selective OTN and DWDM Bypass
Complete Multi-Layer L1+L2+L3 Architecture

Network Optimization & Modelling
- MATE Design
- MATE Live
- 3rd Party Applications

EMS/NMS & Service Provisioning
- Network
- Provisioning
- Optical
- Performance

Cisco Prime Central

Future: Netconf / YANG

Cisco Prime Central

Configlets
- PCEP
- BGP-LS Netflow, CLI, SNMP

XML
- CLI, SNMP

Future: Netconf / YANG

Cisco Prime Central

NCS 4000
- GMPLS (OTN)
- GMPLS (WSON)

40G Packet

100G OTN Private Line

Cisco Prime Central

CTC

Future: Netconf / YANG

Cisco Prime Central
Bringing the Layers together – CP Progression

• Simplest Form – Control Plane (CP) leverages signaling to automate what is done manually today.

PMO
• Independent IP/MPLS CP
• Independent Optical CP – WSON
• Wall separating layers
• No real information sharing

Multi Layer CP (nLight)

• Open the Wall
• Leverage Layered CP
• Insert ML Signaling via UNI
• Share Relevant Layered Info

SDN
• Remove the Wall
• Centralize CP
• Leverage Layered CP
• Application Driven
• Global View - Optimization
Use Case 1 – Global Network Planning, Design and Optimization

- ML network design (Multi Domain)
- ML network collection online
  - Topology
  - Circuits
  - Resources
- Offline Network Analysis
  - Impact Analysis
  - What if Scenarios
  - ML Restoration feasibility
  - ML Optimization
  - Coordinated Maintenance Feasibility
- Online Network Config or user config
- Vendor Agnostic leveraging Industry Proven tools and algorithms

Reduce Op / Cap EX, improve Availability
ML Optimization

10% interface Savings
18% interface Savings

Optical Restoration – A Spectrum of Options

- **WSON Restoration Only**
  - WSON Optical Restoration

- **WSON Restoration with UNI**
  - WSON Optical Restoration
  - UNI

- **Distributed ML Restoration**
  - WSON Automated Provisioning
  - UNI

- **Centralized ML Restoration**
  - WSON Automated Provisioning
  - UNI
Use Case 2 – Service Turn Up

**nLight CP**
- Supports Multi Layer Service Turn Up
- Leverage Constraint based routing across all layers

**Single Domain Single Vendor**

**SDN**
- Support Multi Layer Constraint based Service Turn Up
- Global impact assessment across all layers
- Multi Domain / Multi Vendor

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Reduce Op EX, improve Availability, Increase Service Velocity
Use Case 3: ML Restoration

**nLight CP**
- Optimized for Local / DWDM faults
- Fastest for Initiation of Protection and Restoration
- Highest availability—no connectivity concerns
- Optical Restore is best effort unless designed for any to any

**SDN**
- Optimized Disaster Recovery / Topology Changes
- High Availability - will leverage Distributed
- Higher Restore SLA based on Global view

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Reduce Op / Cap EX – increase utilization
Multilayer restoration

MLR-O: restoration from failures in the optical domain, that can leverage the same router interfaces at both ends
MLR-P: restoration from router port failures, or the link between the router and the ROADM.
MLR-A: restoration of edge router capacity from a failure of an aggregation router, or a core router.
MLR-C: restoration of core network topology from failure of a core router.
MLR-D: recovery from a large scale disaster that may involves an entire PoP, multiple fiber links or multiple routers.
Analyze: All Single Fiber Failures without MLR-O

- Fail fiber spans one at a time (in this example, the top one)
- Typical causes: fiber cut, amp failure, human error
- Assume traffic is protected at the IP layer, therefore extra capacity is needed.
- This (usually) means extra interfaces.

![Diagram showing network topology with redundant interfaces highlighted.]

Key points:
- 260G + 180G
- 180G + 180G
- 180G + 130G
- Redundant interfaces
Result: All Single Fiber Failures without MLR-O

- Populate worst-case quantity of required interfaces for each span
- **38** total interfaces
- These interfaces provide protection against optical and interface failures

This is how the IP network is typically sized today

![Network Diagram](image-url)
Example – with nLight MLR-O

- Same example introduced above.
Example: with nLight MLR-O
First step: immediate IP protection

- Fiber failure causes traffic to re-route at L3 using available capacity.
- Using Pre-FEC proactive protection, traffic can switch in less than 1 millisecond.
- Premium traffic can be prioritized to use available bandwidth.
- Congestion may occur for low priority traffic for a couple of minutes max.
Example – with nLight MLR-O

Second step: optical restoration under MLR control

- nLight MLR will restore the failed wavelengths in a few seconds by signaling a new path.
- The same interfaces are used, so no extras are required.
- Congestion for low priority traffic disappears. Network is at full capacity.
Constraint Based Routing with MLR-O

[Router A] – “I need a wavelength to Router B, disjoint from the Blue wave
[Router A] – “Fiber cut! I will re-signal with the same constraint.”
[Router A] – “Another fiber cut! I will re-signal with the same constraint.”
[NCS 2000] – “I don’t have a path that meets your constraints.”
[Router A] – “OK. I’ll relax the diversity constraint and signal again.”
nLight Multi-Layer Restoration for Port Failures (MLR-P) : Example

- Same example introduced above/before.
Example – without MLR-P

- Assuming MLR-O is active, how do we protect against interface failures?
- One additional link per span is needed to protect against interface failures.
- Two interfaces per router are added (one for each router peer).
- Directional, Colored ROADM ports require that these interfaces be ‘pre-deployed’ – one per direction.
One spare interface per router can protect against failure of any interface on any connected span.

nLight ROADM makes this possible via dynamic circuit re-provisioning.

Four additional interfaces are required vs. eight without MLR-P.
Example – with nLight MLR-P

• Interface failure brings down one link.

• nLight re-routes link to spare interface, using same optical path and same far end interface.
Example – with nLight MLR-O and MLR-P

- MLR-O requires 0 additional interfaces
- MLR-P requires 4 additional interfaces
- Total: 16+4=20 interfaces
- 47% savings over IP protection only (20 vs. 38 interfaces)
The Complete MLR Process

1. Immediate IP protection for premium traffic
2. Localize failure at both ends (LMP)
3. If between router A and ROADM A – run MLR-P @ A
4. If between router B and ROADM B – run MLR-P @ B
5. Otherwise – run MLR-O
ML Bypass Optimization + ML Restoration - Optical

45% interface Savings
50% interface Savings

ML Bypass Optimization + ML Restoration – Optical & Port

62% interface Savings
58% interface Savings

Use Case 4: ML Re-Optimization

- ML Network Optimizations:
  - Optimal routes after Restore trigger cleared
  - Stranded BW
  - Congestive Spans
  - Router By Pass
  - “Hardwired” Interfaces
- Topology or non Topology Changing
- User selectable time frames or event driven

Reduce Op / Cap EX, improve Availability, increase network longevity
Re-optimization

Use Cases

- Manual reoptimization – triggered by L3 operator
- Manual reoptimization test – allowing the operator to check how the network could be reoptimized without actually changing anything
- Periodic reoptimization – every X hours/day or at certain times of the day/month
- After recovery from a physical failure that was restored via multi-layer restoration
- Reopt requested by the optical layer (via a path-error signaling message).

- Reduce stranded BW
- Reduce congestion on L0 link
- Remove regen
- Reduce path length (even if latency is a non-issue)
- Redistribute spectrum (critical for FlexSpectrum)
Use Case 5: Co-ordinated Maintenance

- Select Maintenance Node
- Verify level of service impact by maintenance event
- Route traffic around affected node
  - Wavelength and Packet
- Notify time to start event
- Restore traffic once maintenance complete

Reduce Op EX, improve Availability, improve SLAs
Summary
Enabling the Evolved Programmable MultiLayer Network

• Dynamic Packet Layer
  – Proven, Scalable, and Robust IP/MPLS control plane

• Dynamic Multi-Layer Control Plane
  – Information sharing - the network is the database
  – Constraint-based multi-layer provisioning

• Dynamic Optical Foundation
  – Massively Scalable OTN
  – Touchless, Fully Programmable ROADM
  – Mature, feature rich, widely deployed optical control plane WSON → SSON
A Phased Approach to SDN - Building Trust in the Network

nLight Multi-Layer Control Plane

Multi-Layer Information Sharing and Provisioning
Leverage GMPLS-UNI

Building Trust

Dynamic Online Multi-Layer Control
Dynamic Online Multi-Layer Capabilities
Hybrid Control - best of distributed and centralized

Network Optimization
Powerful offline analysis of real-time data
Cisco Quantum WAN
Orchestration – Cisco MATE
Months to Minutes – How do we get there?

Provisioning Process

IP

Manual data collection, analysis and circuit request

Transport

Offline transport analysis and manual provisioning

Quantum N.O.S.
MATE Design. MATE Live.

WSON → SSON

Layer Optimization

nLight Multi-Layer Control Plane

Multi-Layer Optimization

What’s Next?

Dynamic Online Multi-Layer Optimization

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EPN: Enabling Application Driven Networks

Bandwidth-on-Demand

User Application

Multi-Layer 3D Visualization

Multi-Layer Network Optimization
Agenda

• Introduction
• Technology Trends
  – Packet
  – OTN
  – Photonic Layer
  – Control Plane
• Multi-Layer network architecture
• Summary
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