What You Make Possible
Advances in IP+Optical and Multi-Layer Integration
BRKOPT-2661
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Agenda

- Introduction to IP+Optical
- New ROADM Trends to support seamless integration
- Multi-layer Control Planes
- IP+Optical Architectures and Management
- Conclusion
Introduction to IP+Optical
Circuit to Packet Migration

- Massive change in SP traffic make-up in next 5 years*
- SP revenue shifting from circuits to packet services**
  - 5 yrs → ~80% revenue derived from packet services
  - Packet traffic increasing at 34% CAGR*** (mobility, video and cloud)

*ACG Research 2011, **Cisco Research 2010, ***Cisco VNI 2011
Changing Traffic Patterns Drive Architecture Evolution
No Longer North and South; now East and West
How Technology Affects Economics
Percent of CAPEX, cost per bit

- The higher data rate means more complexity in optics and higher optical cost
- The ratio of L3 and Optical cost is changing with the data rate

Routing is 8% of Total Circuit spend, Down from 35% 7 years ago
IP+Optical Business Drivers

- Increase Service Velocity
- Collapse Layers – reduce devices, space, power & OpEx
- Hybrid IP+TDM capabilities
  - Support legacy services
  - Migrate to single wavelength
- Eliminate interconnect optics cost
IP+Optical Business Drivers, Continued

- Flexibility of L3 and Optical results in the following benefits:
  - Reduce port numbers
  - Optical bypass opportunity
  - Greater flexibility for Layer 3 services
  - Additional network connectivity options, lower CAPEX
  - All network changes driven by software
  - Increase average utilisation per link
  - Release underutilised connections
What does IP+Optical Mean?

Distinct aspects define a true added value IP+Optical solution

- Data Plane integration

- Control Plane Integration
  - Multilayer Control Plane

- Management Plane Integration
Standards Bodies and Organisations

Charter: Evolution of the Internet (IP) Architecture
Active Participants:
• Service Providers
• Vendors

Charter: Global Telecom Architecture and Standards
Member Organisations:
• Global Service Providers
• PTTs, ILECs, IXCs
• Telecom equipment vendors
• Governments

Charter: Development of Optical Networking Products and Services
Member Organisations:
• PTTs, ISPs, ILECs, IXCs
• Optical Networking Vendors

Charter (802.3 working group):
Define the physical layer and data link layer’s media access control (MAC) of wired Ethernet
Member Organisations:
• Component Vendors
• Networking Vendors
Standards Drive Adoption

- **Control Plane**
  - IETF

- **IEEE**
  - **Client Interfaces**
    - Layer 2 interoperability
  - **Transport Networks**
    - Layer 1/0 interoperability

- **OIF**
  - **Hardware Vendors**
    - Component Interoperability, Commonality
  - ITU
  - **IEEE**
New ROADM Trends to Support Seamless Integration
What is a ROADM?
A ROADM is a Wavelength Switch

### Traditional OADM
- **A fixed number** of channels
- **A fixed set** of channels
- Physical Ring Only (2 Degree)

### Reconfigurable OADM
- **Any number** of channels (0 to 40/80)
- **Any set** of channels, directional
- Physical Ring (2D) or Mesh (Multi-Degree)
... because ROADM ports were coloured and directional.

Coloured Add/Drop
Fixed port frequency assignment
One unique frequency per port

Directional Add/Drop
Physical add/drop port is tied to a ROADM “degree”

Due to these restrictions, a change in direction or frequency of an optical circuit required a physical change (move interface to different port) at the endpoints.
Colourless and Omni-directional Capabilities
Add Touchless flexibility, and hence Programmability, to ROADM networks

Colourless Add/Drop
No port-frequency assignment
Any frequency, any port

Omni-Directional Add/Drop
Add/Drop ports can be routed to/from any ROADM degree

With **Colourless** plus **Omni-Directional**, the frequency and direction of the signal can be changed, without requiring a change of ROADM add/drop port, therefore no truck rolls.
But…Colourless and Omni-directional introduce wavelength contention at the add/drop stage. Need a **Contentionless** architecture.

Directional Add/Drop ROADMs are by definition Contentionless

Contentionless allows multiple instances of the same frequency to add/drop from one unit.

With **Contentionless**, \( N \) instances of a given wavelength (where \( N = \) the number of line degrees in the ROADM node) can be add/dropped from a single device, eliminating any restrictions on dynamic wavelength provisioning.
Tuneable lasers and coherent receivers are also key enablers of IP+Optical

Transmitter can tune its laser’s frequency to any channel in the ITU grid.

Receiver can select any channel from of a composite (unfiltered) signal.

Tuneable lasers work with colourless add/drop to enable touchless changes in the frequency of an optical signal. Coherent receivers simplify the construction of colourless and omni-directional ROADM nodes.
Key Takeaways

- Colourless and tunable optics allow changing wavelength with no physical re-cabling
- Allow for any to any switching in the optical domain
- Allow for re-routing in the optical domain
- Omni-directional and tunability
- Use the C-band spectrum to its full capacity

These features open the door for a new agile DWDM control plane
Multilayer Control Planes
The Optical Layer – Current

Manual Patching

- Manual provisioning of each node
- Manual patching of each node
- High OpEx
- Truck rolls to every node
What Should an Optical Control Plane do?

Elements of an OCP

<table>
<thead>
<tr>
<th>Resource Discovery</th>
<th>Topology Discovery</th>
<th>Traffic Provisioning</th>
<th>Traffic Restoration</th>
<th>Network Restoration</th>
<th>Network Optimisation</th>
</tr>
</thead>
</table>

Increasing Complexity
# Agile Control Plane Requirements

## Requirements

<table>
<thead>
<tr>
<th>Tunability</th>
<th>Colourless</th>
<th>Omni-Directional</th>
<th>Impairment-aware</th>
</tr>
</thead>
</table>

Enabling Zero Touch End to End Solution
GMPLS Introduction

- Generalised control plane for different types of network devices
  - Packet-Switch Capable (PSC)
  - Layer-2 Switch Capable (L2SC)
  - Time-Division-Multiplex Capable (TDM)
  - Lambda-Switch Capable (LSC)
  - Fibre-Switch Capable (FSC)
- Two major models: peer (NNI) and overlay (UNI)
- Different label formats depending on network type
  - We focus on LSC here
GMPLS Introduction (Cont’d)

- Based on initial RSVP-TE, OSPF-TE and ISIS-TE extensions
- Strict separation of control and forwarding planes
- Supports bi-directional LSPs
- IP based control plane (no LDP)
- No IP based forwarding plane
What is Wavelength Switched Optical Network (WSON)?

- It is a GMPLS control plane which is “DWDM aware”:
  - LSP are wavelength and,
  - the control plane is aware of optical impairments

- WSON enables lambda setup on the fly
- WSON enables lambda re-routing
- WSON enables a lambda revalidation against a failure reparation
Cisco WSON Parameters – Embedded Optical Layer Intelligence

Foundation for Multi-layer Information Exchange

Linear Impairments
- Power Loss
- Chromatic Dispersion (CD)
- Polarisation Mode Dispersion (PMD)
- Optical Signal to Noise Ratio (OSNR)

Non linear Optical impairments:
- Self-Phase Modulation (SPM)
- Cross-Phase Modulation (XPM)
- Four-Wave Mixing (FWM)

Topology
- Lambda assignment
- Route choices (C-SPF)

Interface Characteristics
- Bit rate
- FEC
- Modulation format
- Regeneration Capability
Automating the Optical Layer with WSON

Dynamic Service Activation with Colourless, Omnidirectionality and GMPLS

- Auto provisioning wavelength on demand via GMPLS
  - Auto restoration via ROADMs and WXC
  - Lower OpEx even further
  - No truck rolls
WSON Restoration

- **Trigger**
  - Link Failure
  - Signal Failure

- **Route Discovery and Validation**
  - Constrained OSPF algorithm
    - First try original wavelength, then others
  
- **Switch**
  - Re-tune interface wavelength (if necessary)
  - Provision VOAs and WXC ports
Wavelength Switched Optical Network

Auto Restoration
Wavelength Switched Optical Network

Auto Restoration

Fibre Cut!
Wavelength Switched Optical Network

Auto Restoration

Embedded WSON intelligence locates and verifies a new path
Restoration is Slower than Protection

- If rapid failure detection and recovery is needed, it is assumed that existing packet IP/MPLS mechanisms (e.g., BFD, IP-FRR, TE-FRR, LDP-FRR, mLDP-FRR, fast convergence) will be used for protection and recovery.
- IP+Optical Solutions can use Proactive Protection
- Protected services (Y-cable, PSM, FibreSwitch) should be used for valuable traffic to provide rapid protection at the optical layer.
- Restoration is Best Effort.
What if we Integrate IP Control Plane with WSON?

- Reduce Optical Circuit Turn Up Time
- On Demand Bandwidth Provisioning
- Constrained Circuit Request to Avoid Shared Risk
- Alarm Correlation
- Network Optimisation
Multi Layer Control Plane

Two key models

Peer Model – Optical NEs and Routing NEs are one from the control plane perspective, same IGP.
- Does not respect operational boundaries; does not scale

Overlay Model – Having different Control Planes per Layer and signalling between them
- Respects Boundaries and Scales
WSON and IP Control Plane to Communicate - GMPLS UNI

Router

GMPLS UNI

ROADM

WSON

GMPLS UNI

Router
GMPLS – User Network Interface

- User-Network Interface (UNI) to implement an overlay model between two networks – with limited communication between them
- Enables a Cisco router to signal paths dynamically through a DWDM network
- Paths may be signaled with diversity requirements
- Two UNI components
  - Client: UNI-C
  - Network: UNI-N
- Building block for multi-layer routing

* Formerly known as iOverlay
Link Management Protocol (LMP)

- Performs two core functions
  - Control channel management
  - Link property correlation
- Runs over UDP with mechanisms for reliable message transmission
- Includes mechanisms for LMP neighbour discovery
- Most messages exchanged over control channel
- Can also provide link connectivity verification and fault management
RSVP

- Client Requests connections from optical network using GMPLS RSVP-TE Extensions
- RSVP signalling is identical to GMPLS extensions specified in RFC 3473 except where noted in RFC 4208.
GMPLS UNI - IP Control Channel

Optical Network

Control Network (IP-based)

IP Control Channel (IPCC)
GMPLS UNI – Reference Model (IP+Optical)

UNI honors administrative boundaries while allowing controlled interaction
Path Computation and Signalling (no ERO)

- UNI-C (Head)
  - Initiates signalling (default lambda)
  - No explicit path (ERO) defined / signaled
  - Signalling initiated towards remote UNI-C (optical loopback or optical link address)
  - Bi-directional path (upstream and downstream labels)

- UNI-N
  - Arrival of PATH message without ERO triggers path computation to destination across optical domain
  - PATH calculations performed at the UNI-N head
  - Establishment of optical path (trail) required for UNI signalling to proceed
Signalling – Path Setup

1. Head initiates tunnel signalling
2. UNI PATH (upstream label = default lambda)
3. Trail Upstream PATH
4. Optical impairment check
5. Trail Upstream RESV
6. Trail established
7. UNI RESV (Label = lambda)
8. Tunnel established

UNI-C

UNI-N

Optical path computation, trail signalling initiated
Trail Downstream PATH
Trail Downstream RESV
Per-hop optical parameters
Optical impairment check
Trail established
UNI RESV (Label = lambda)
Tunnel established

UNI-N

UNI-C

Head initiates tunnel signalling
UNI PATH ERROR (upstream label = lambda)
Trail established
UNI PATH (upstream label = lambda)
UNI PATH (upstream label = lambda)
UNI RESV (Label = lambda)
# Generalised Label for Lambda-Switch-Capable (LSC) Label Switching Routers

<table>
<thead>
<tr>
<th>Grid</th>
<th>Channel Spacing</th>
<th>Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>ITU-T DWDM</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ITU-T CWDM</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Future Use</td>
<td>3 - 7</td>
<td></td>
</tr>
</tbody>
</table>

- **Grid** – Optical grid as defined in ITU-T G.694.1
- **Channel Spacing** – Spacing between DWDM channels in GHz
- **Identifier** – Per-node distinguisher between lasers than can transmit same lambda
- **n** – value used to compute frequency (two’s complement)

<table>
<thead>
<tr>
<th>DWDM Channel Spacing (GHz)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>12.5</td>
<td>4</td>
</tr>
<tr>
<td>Future Use</td>
<td>5 - 15</td>
</tr>
</tbody>
</table>

Frequency (THz) = 193.1 THz + n * channel spacing (THz)
### GMPLS-UNI Example Setup

<table>
<thead>
<tr>
<th>Node</th>
<th>L3/Packet ID</th>
<th>Optical Router ID</th>
<th>L3/Packet Link Address</th>
<th>Optical I/F Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head UNI-C</td>
<td>1.1.1.1</td>
<td>10.58.46.1</td>
<td>10.0.0.1</td>
<td>100.11.11.11</td>
</tr>
<tr>
<td>Ingress UNI-N</td>
<td>n/a</td>
<td>10.58.46.2</td>
<td>n/a</td>
<td>100.12.12.12</td>
</tr>
<tr>
<td>Egress UNI-N</td>
<td>n/a</td>
<td>10.58.47.2</td>
<td>n/a</td>
<td>100.19.19.19</td>
</tr>
<tr>
<td>Tail UNI-C</td>
<td>2.2.2.2</td>
<td>10.58.47.1</td>
<td>10.0.0.2</td>
<td>100.20.20.20</td>
</tr>
</tbody>
</table>
Sample Base GMPLS UNI Config – Head

LMP Properties
- Imp
  - gmpls optical-uni
  - controller dwdm0/2/0/0
  - neighbor nbr_A

Optical I/F of LMP Neighbour
- neighbor link-id ipv4 unicast 100.12.12.12
- neighbor interface-id unnumbered 13

UNI-C Optical link address
- link-id ipv4 unicast 100.11.11.11
- !

Control Channel
- neighbor nbr_A
  - ipcc routed
  - router-id ipv4 unicast 10.58.46.2
- !

Optical Router ID
- router-id ipv4 unicast 10.58.46.1
Sample Base GMPLS UNI Config – Head (Cont’d)

RSVP Refresh

interface HundredGigE0/2/0/0
  signalling refresh optical interval 3600
  signalling refresh optical missed

mpls traffic-eng
  interface HundredGigE0/2/0/0
    gmpls optical-uni
      controller dwdm0/2/0/0
      tunnel-id 1
      destination ipv4 unicast 100.20.20.20
      path-option 10 no-ero lockdown
Sample Base GMPLS UNI Config- Tail

LMP Properties

Control Channel

Optical Router ID

LMP Properties

Control Channel

Optical Router ID

imp

gmpls optical-uni

tail

ccontroller dwdm0/3/0/0

neighbor nbr_A

neighbor link-id ipv4 unicast 100.19.19.19

neighbor interface-id unnumbered 13

link-id ipv4 unicast 100.20.20.20

!)

neighbor nbr_A

ipcc routed

router-id ipv4 unicast 10.58.47.2

!)

router-id ipv4 unicast 10.58.47.1
Sample Base GMPLS UNI Config- Tail (Cont’d)

RSVP Refresh

interface HundredGigE0/3/0/0
    signalling refresh optical interval 3600
    signalling refresh optical missed 24

TE Link Properties

mpls traffic-eng
    interface HundredGigE0/3/0/0

No GMPLS Tunnel configuration

But must tell interface to “listen”

gmpls optical-uni
    controller dwdm0/3/0/0
1. Router requests a circuit between Source and Destination Routers Interfaces
Provisioning using GMPLS UNI Example

Circuit Request

1. Router requests a circuit between Source and Destination Routers Interfaces
2. Using GMPLS UNI I/F Router signals UNI-N system requesting path to destination
Provisioning using GMPLS UNI Example

Circuit Request

1. Router requests a circuit between Source and Destination Routers Interfaces
2. Using GMPLS UNI I/F Router signals UNI-N system requesting path to destination
3. UNI-N initiates DWDM CP (WSON) and finds best path based on Diversity contraints
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2. Using GMPLS UNI I/F Router signals UNI-N system requesting path to destination
3. UNI-N initiates DWDM CP (WSON) and finds best path based on Diversity constraints
4. Destination UNI-N Node signals Destination router and requests IPoDWDM interface to be set to specific wavelength
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5. Head End UNI-N signals Head End router to set IPoDWDM interface to specific wavelength
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2. Using GMPLS UNI I/F Router signals UNI-N system requesting path to destination
3. UNI-N initiates DWDM CP (WSON) and finds best path based on Diversity constraints
4. Destination UNI-N Node signals Destination router and requests IPoDWDM interface to be set to specific wavelength
5. Head End UNI-N signals Head End router to set IPoDWDM interface to specific wavelength
6. Path is up and interfaces are ALLOCATED
Layer Interaction – Provisioning
Dramatically Increase Circuit Turn-up Velocity

– Yesterday → Months
  L3 team requests circuit of L0 team, with specific criteria
  L0 team verifies available path, matching request criteria
  L0 team verifies performance and resources
  L0 / L3 teams coordinate circuit turn-up

– Today - GMPLS → Minutes
  Client signals circuit request along with criteria
  L0 signals wavelength to use or path error message
  Circuit is turned up
Putting it Together
WSON, GMPLS UNI and IPoDWDM Proactive Protection
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Putting it Together
WSON, GMPLS UNI and IPoDWDM Proactive Protection

GMPLS UNI
Router

GMPLS UNI
Router

GMPLS UNI
Router

GMPLS UNI
Router

Traffic Flow
Putting it Together
WSON, GMPLS UNI and IPoDWDM Proactive Protection

GMPLS UNI

Router

GMPLS UNI

Router

Router

Route

t

Traffic Flow
Putting it Together
WSON, GMPLS UNI and IPoDWDM Proactive Protection

GMPLS UNI
Router

GMPLS UNI
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Router

Traffic Flow
Putting it Together
WSON, GMPLS UNI and IPoDWDM Proactive Protection

Fibre Cut!
Embedded WSON intelligence locates and verifies a new path

Router

GMPLS UNI

Router

GMPLS UNI

Route

Traffic Flow
Putting it Together
WSON, GMPLS UNI and IPoDWDM Proactive Protection

All paths with purple wavelength
In use!!!

Traffic Flow
Putting it Together
WSON, GMPLS UNI and IPoDWDM Proactive Protection

GMPLS UNI

Router

GMPLS UNI

Router

ROADM instructs client to re-tune its wavelength

Colourless, Omni-Directional ROADM switches the path

Traffic Flow
Putting it Together
WSON, GMPLS UNI and IPoDWDM Proactive Protection

GMPLS UNI

Router

Route

GMPLS UNI

Router

Traffic Flow
Inefficiencies in Layer 2/3 Network

- **Impacts SLA**
  - downtime, latency, loss, predictability of service

- **Impacts bottom-line**
  - SLA penalty, unoptimised capacity, support complexity
Basis for nLight Control Plane

- The solution to these problems are simple
- If the client layer knows basic information from the server layer: SRLG, latency…
- To-date, this information is invisible to the client layer
- We need to allow for information sharing between Client and Server
Multi Layer Control Plane

Two key models

Peer Model – Optical NEs and Routing NEs are one from the control plane perspective, same IGP.
  - Does not respect operational boundaries; does not scale

Overlay Model – Having different Control Planes per Layer and signalling between them
  - Respects Boundaries and Scales

Peer Model

Overlay Model

Single Domain

Routed Domain

Optical Domain

Information Exchange
nLight Architecture

- Overlay client uses service from Server layer (i.e. IP/MPLS)
- Two independent layers decoupled
Benefits of IGP Decoupling

- The IGP’s of each layer are de-coupled
  - L3 network runs multi-level ISIS
  - ROADM network runs OSPF

- Divide et Impera Benefits
  - Scale
  - Operational expertise
  - Organisational segmentation
Multilayer Control Plane - nLight

- GMPLS UNI extension to include SRLG and Coordinated maintenance functionality
- GMPLS UNI extension to support next generation of Multi-rate/Multi-Modulation/Multicarrier HS Optics
- Automatic Bandwidth service from MPLS CP and WSON CP will be the end goal to deploy a true Multi-Layer Network
- Integration of an L1/L3 awareness in a Network Planner Prime module
Information Flowing through nLight with GMPLS UNI

- When signalling 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 optimisation upon shortest latency
  - a bound on latency not to exceed
  - an optimisation upon lowest optical cost
  - optical restoration
  - optical re-optimisation
Information Flowing through nLight GMPLS UNI

- For each circuit it signals, a client may be informed of:
  - Circuit-ID – unique identifier in server context
  - SRLG’s along the circuit
  - Latency through the server network
  - Path through the server network
    Information continuously refreshed
- A client may be informed of server topology/resource

Agile IP layer
CircuitID, SRLG, Latency…

Agile DWDM layer
Policy Controlled by the Server Layer
nLight Resolves the Inefficiencies

- **Efficient IP/MPLS FRR**
  - thanks to SRLG discovery

- **Enforcement of disjointess or same-path requirements**
  - thanks to SRLG/Circuit-ID disjointness

- **Efficient diagnostics**
  - latency discovery

- **Efficient operation**
  - multi-layer maintenance coordination
Intelligent Information Exchange
Proactive Protection, GMPLS, Control Plane

Client Requests
- Proactive Protection
- Circuit from A to Z
  - Matching Path
  - Disjoint Path
  - SRLG Avoidance
  - Max Latency

Server Information
- Pre-FEC Threshold Crossing
- Network Topology & Feasibility
  - Circuit ID and Path
  - SRLG database
  - Path Latencies

IGP
QoS
SLA's
Peering
Addressing

Interface Integration
G.709
GMPLS
UNI
nLight Control Plane
UNI Extensions

OSNR
CD / PMD
power levels
non-linear impairments
physical topology
IP+Optical Architectures and Management
The Traditional Approach

• Split Management: Router NE management + Transport NE management
  • i.e. WDM Power levels, OTN overhead, and alarms not available on the router
  • No topology or performance information sharing between device types
• Transponder integrated in the router
• Manage via CLI, SNMP or EMS system of DWDM transport
• Power levels, OTN overhead, PM, and alarms available in real-time on the router
Transponder in Router

Proactive Protection

- Reactive Protection
- Proactive Protection

- Working route
- Fail over
- Protect route

- FEC Limit
- Pre-FEC Bit Errors
- Time

- Router
- Transponder
- ROADM
Virtual Transponder

Transponder Virtualised onto the Router Interface

- Retains existing operational model
- Respects boundaries between packet / optical administrative groups

Router Management
- L2/L3 Interface Information
- Routing Protocols
- IP Addressing
- Security

DWDM Management
- L1 Interface Information
- Wavelength Usage
- Power Levels and Thresholds
- Performance Monitoring
Virtual Transponder
General View
Virtual Transponder
View Router G709 and optical characteristics

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Virtual Transponder

Setting up OCHTrail
Optical Shelf Concept
Solving the Moore vs. Shannon dilemma

- Realise benefits from combining Optics + Processing...when it makes sense. But for the future...
- Decouple Optics from Processing
  - Space / Size
  - Lifecycle
- Zero Cost interconnect
- Value add functionality (take advantage of OEO)
  - Pack waves efficiently
- Maintain unified management
IP+Optical: Satellite
Router Interface Virtualised onto the Transponder

- Transponder becomes an extension of the router
- Power levels, OTN overhead, and alarms available in real-time on the router
- DWDM interface controlled and monitored by router CLI or OTN MIB
- Control Plane Interaction
IP+Optical Satellite
Proactive Protection

ASR 9000

100GE

ONS 15454 M6

Protection Trigger

IP-over-DWDM

working route

protect route

Hitless Switch

FEC Limit

Protection Trigger

Router Bit Errors

Pre-FEC Bit Errors

Time
IP+Optical Network Management

• A modular suite of applications

• A-to-Z management for next-generation packet and transport networks

• Designed for lower Total Cost of Ownership

Crucial to the usability of the NGN, control plane alone is not enough…
Summary

- Packet traffic increasing
- IP+Optical decreases expenses while streamlining services
- New ROADM trends to support optical agile networks enabling multilayer control planes
- Multilayer control planes add network automation and resiliency as well as decrease TCO
- New architectures enable next generation networks
### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-SPF</td>
<td>Constrained Shortest Path First</td>
</tr>
<tr>
<td>CD</td>
<td>Chromatic Dispersion</td>
</tr>
<tr>
<td>CP-DQPSK</td>
<td>Coherent Polarisation-Mux Differential Quadrature Phase Shift Keying</td>
</tr>
<tr>
<td>DSP</td>
<td>Digital Signal Processing</td>
</tr>
<tr>
<td>DWDM</td>
<td>Dense Wave Division Multiplexing</td>
</tr>
<tr>
<td>ELEAF</td>
<td>E-Large Effective Area Fibre</td>
</tr>
<tr>
<td>FEC</td>
<td>Forward Error Correction</td>
</tr>
<tr>
<td>FRR</td>
<td>Fast Re-Route</td>
</tr>
<tr>
<td>FWM</td>
<td>Four Wave Mixing</td>
</tr>
<tr>
<td>GMPLS</td>
<td>Generalised Multi Protocol Label Switching</td>
</tr>
<tr>
<td>IETF</td>
<td>Internet Engineering Task Force</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunications Union</td>
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<tr>
<td>LFA</td>
<td>Loop Free Alternate</td>
</tr>
<tr>
<td>LSP</td>
<td>Labeled Switch Path</td>
</tr>
<tr>
<td>NNI</td>
<td>Network-Network Interface</td>
</tr>
<tr>
<td>OCP</td>
<td>Optical Control Plane</td>
</tr>
<tr>
<td>OIF</td>
<td>Optical Internetworking Forum</td>
</tr>
<tr>
<td>OSNR</td>
<td>Optical Signal to Noise Ratio</td>
</tr>
<tr>
<td>OTN</td>
<td>Optical Transport Network</td>
</tr>
<tr>
<td>PMD</td>
<td>Polarisation Mode Dispersion</td>
</tr>
<tr>
<td>QAM</td>
<td>Quadrature Amplitude Modulation</td>
</tr>
<tr>
<td>ROADM</td>
<td>Reprogrammable Optical Add/Drop Multiplexer</td>
</tr>
<tr>
<td>SLA</td>
<td>Service Level Agreement</td>
</tr>
<tr>
<td>SMF</td>
<td>Single Mode Fibre</td>
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<tr>
<td>SRLG</td>
<td>Shared Risk Link Groups</td>
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<tr>
<td>TDM</td>
<td>Time Division Multiplexed</td>
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<tr>
<td>TE</td>
<td>Traffic Engineering</td>
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<tr>
<td>UNI</td>
<td>User-Network Interface</td>
</tr>
<tr>
<td>WSON</td>
<td>Wavelength Switched Optical Network</td>
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<tr>
<td>WXC</td>
<td>Wavelength Cross Connect</td>
</tr>
<tr>
<td>XPM</td>
<td>Cross Phase Modulation</td>
</tr>
<tr>
<td>YoY</td>
<td>Year over Year</td>
</tr>
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</table>
Final Thoughts

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