Outline

- The case for IP optimized transport
- Changes to the architecture of the network
- Cisco solution and direction
- Network Management
- Summary
Overall Traffic Growth Is Straining All Known Network Architectures

For Perspective:

1 Exabyte = 5 X All the World’s Printed Matter

5 Exabytes = All Words ever Spoken

Legacy applications moving to IP

- Video – SD, HD, Broadcast Cable
- Voice

New applications almost exclusively IP

- Video - On Demand, DVRs, Switched Digital, Video conferencing …
- Audio – Streaming audio, Internet radio, Digital juke boxes, etc….
- High-Speed Data, Internet
- Over-the-Top Content providers—i.e., YouTube

Household Bandwidth Needs in 2010:

- Applications: HDTV + SDTV + PVRs + HSD + VoIP-Phones

Twenty such homes would generate more traffic than traveled the entire Internet backbone in 1995

*Source: Cisco Estimates, Ovum, Gartner, IDC, Merrill Lynch, MRG, MPA, Public Company Data
Growth Trends in IP Traffic and DWDM System Throughput

**DWDM needs 40G now to keep pace with IP growth.**
100G will likely be needed before end of decade.
Where does this take us?

- **Higher bandwidths** are needed to address this growth:
  1. 10 Gig networks beginning to feel the strain
  2. Cannot rely on L2/L3 aggregation: LAG 4 X 10G ≠ 40G
  3. Cannot rely on L1 aggregation: DWDM ports are not unlimited

- **Increase wavelength** capacity as soon as viable:
  1. Move to higher data rates per lambda, i.e. 40G and 100G
  2. BUT must operate over existing infrastructure
  3. AND ideally with equivalent performance to 10G
  4. Requires advanced optical modulation schemes

- **Remove** all unnecessary network layers leaving only:
  1. Service layer (IP)
  2. Transport layer (DWDM)

- **Integrate** DWDM technology on Router: IPoDWDM
Typical IP Network + Optical Network

- Transponders converting short reach to \( \lambda \)
- Electrical XC
- P2P DWDM
- Electrical switching – OEO conversions
- Manual patching of connections
- Core Router
- Router blind to L0 issues
Cisco IPoDWDM Architecture

- Integrated transponders
- Core Router
- Optical control plane
  Exchanging data w routers
- Mesh ROADM
- Router aware of L0
- Photonic switching – no OEO conversions
- ROADM
Cisco IPoDWDM Strategy

- **Element Integration**
  - Integrate transponder functionality onto routing platforms (10GE, 40G, G.709, EFEC)
  - Integrating photonic switching into DWDM platforms (ROADM / WXC)

- **Control Integration**
  - DWDM aware GMPLS for provisioning of lambdas driven by IP control plane
  - Coordination between layers (e.g. SRLG, NLAC)

- **Management Integration**
  - Separate or integrated management

**SP Benefits**
- Scale & Performance
- Lower CAPEX/OPEX
- Increased Reliability
- Speed to Service

**Cisco IPoDWDM Strategy Diagram**

- CRS-1
- 12000
- 7600

- ONS 15454 MSTP
  - ROADM & WXC

- IP Layer

- DWDM Layer

- Element Integration
- Control Integration
- Management Integration
Immediate Benefits of IPoDWDM solution

- Lower CapEx
  - Elimination of OEOs
- Lower OpEx
  - Space, power, management
- Enhanced resiliency
  - Fewer active components
- Investment protection
  - 40G and beyond, interoperability over existing 10G systems
Replacing TDM layer functions

1. Easy operations (OAM&P)
   – G.709 overheads mimic SONET/SDH functions
   – GMPLS allows optical layer visibility into hard to detect failures
   – Integrated optics allows for low cost optical monitoring

2. Fast protection
   • Control plane provides fast failure indications to optical switches
   • Router based fast reroute (FRR) can be more economical and as fast/reliable as transport layer protection

3. Sub-wavelength grooming & aggregation
   • Not needed if router trunks can fill 10G wavelengths
   • Manage bandwidth at the wavelength level using optical switches
MSTP: Leveraging the Intelligent WDM layer

Open WDM Architecture:

- **Transparent Transmission**
  High-performance (EFEC, adv. mod.)
  Bit-rate Independent
  ‘Alien-Wavelength’ (emerging std.)

- **Operations Friendly**
  G.709 OAMP, tunability, monitoring, GMPLS

- **Network planning flexibility**
  ROADM, Planning tools

IPoDWDM interoperability:

- State-of-the-art performance over MSTP
- Field tested ‘Alien-Wavelength’ over existing (3rd party) WDM Systems
MSTP: Industry First Ethernet Aggregation Integrated into DWDM

- Introducing Ethernet XPonders (pronounced “Cross-Ponder”)
- Single card for Ethernet Add-Drop, muxponder and transponder
- Innovations:
  - Layer-2 Ethernet aggregation of NxGE into 10GE
  - Sub-wavelength add/drop and drop and continue
  - 50 ms resiliency
  - G.709 (WDMPHY): OAMP, EFEC
MSTP: An Open DWDM Layer
Not as hard as it seems

- Public references:
  - Cisco ONS1545 MSTP
  - Nortel CPL (Comcast)
  - Alcatel 1626LM (Embratel)
  - Padtec MetroPad (Embratel)
  - Lucent OLS400 (Dreamhack)
  - Siemens SURPASS hiT7550 (indirectly via SL OEM)
  - Tellabs TITAN 7100 (via published Stratalight interop)

- Other trials:
  - Fujitsu Flashwave (Comcast metro)
  - Ciena CoreStream (Sprint)
  - Huawei 80CH DWDM (China Telecom)
  - Ericsson MHL-3000 (DT)

Not generally a technical barrier – more a political one
40Gig, Plug and Play Circuit Turn Up
“The most difficult part of the whole project was installing Windows on Sigbritt’s PC,” said Hafsteinn Jonsson of Karlstad Stadsnat.
Recent Trends Towards IPoDWDM
Other Router Vendors Following Cisco’s Lead

Fig. 4. Router-to-router test configuration.

10GE WDM PHY demo from Juniper/Adva [OFC08 NME4]
Other vendors also believe this is the Future

Ethernet (IP) Over Optics (WDM) Technology Enables Cost-Efficient Terabit Connection

- Optical transport (and access) will jointly evolve with class of e2e services
- Carrier Ethernet transport will over time substitute Sonet/SDH-based TDM services with improved service features & significant opex savings
- Cross-layer optimization will continue to improve overall cost efficiencies
- IP-over-WDM technologies, along with packetized optical networks, will serve the new Internet connectivity infrastructure for both fixed & mobile communities
Cisco Commitment to IPoDWDM Innovation

- **Interface speed**
  - Cisco 1st to productize 40G
  - Leading 100G effort in IEEE (HSSG)
  - 100G development work in progress

- 100Gbps Switch Fabric, MSC and PLIMs
- 10G, 40G, 100G interfaces
- Target for existing CRS-1 chassis with **no** power/cooling upgrades
- **Reduction of power/G by a factor of 2.5**
- Increased line card scale & new feature development
  - Prefixes, policers, queues, VLANs…
- Ability to run in lower performance and/or bandwidth mode to save power - Green Mode
  - 8% to 15%

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  - Cisco is leading ROADM market
  - Innovative, operationally friendly, mesh ROADM
  - Early to provide configurable add/drop switching
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- **Control plane**
  - Introduced partial control plane (OSPF, NLAC)
  - Experimenting with DWDM impairment aware GMPLS
Careful DWDM layer design with the future in mind

- **Future proof grid**
  - Must accommodate a variety of possible future modulation formats for 100Gbps and beyond
  - Flex Spectrum instead of a fixed grid
  - In the mean time sticking to 100GHz grid is safest

- **In-service upgradeable optical switching nodes**
  - MSTP architecture easy to upgrade as more DWDM links added and more add/drop is needed
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- In-service upgradeable optical switching nodes
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- Open DWDM layer
  - Full support for alien wavelengths in MSTP
  - Working to extend GMPLS to support 3rd party Tx/Rx
  - No need to restrict Tx/Rx innovation to Transport vendor roadmap
DWDM Layer Evolution must be Closely Tied to IP Layer Evolution

**Proactive protection** → demonstrated, working toward product

**SRLG sharing** → working toward product

**Coordinated maintenance** → working toward product

**Flexible bit rate** → trade-off bit rate for regeneration; investigating

**Optical auto bandwidth** → investigating
Proactive Protection

Today’s protection

- Working path
- Protect path
- Switch-over = lost data
- LOF
- FEC limit
- Optical impairments
- Corrected bits
- BER

Proactive protection

- Working path
- Protect path
- Near-hitless switch
- FEC limit
- Protection trigger
- Optical impairments
- Corrected bits
- BER

SR port on router

Transponder

FEC

WDM port on router

WDM

FEC

Today’s protection

Proactive protection
Pre-FEC Preliminary results

- Tested manual/fast cuts, slow OSNR and PMD degradations
- Tested MPLS FRR, IP FRR, ISIS convergence
- In all cases, achieve near zero outage for slow failures

<table>
<thead>
<tr>
<th>Protection Type</th>
<th>Fault</th>
<th>Packet Loss (ms)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Highest</td>
<td>Lowest</td>
<td>Average</td>
</tr>
<tr>
<td>Proactive</td>
<td>Optical-switch (25ms)</td>
<td>11.48</td>
<td>10.99</td>
<td>11.24</td>
</tr>
<tr>
<td>Proactive</td>
<td>Noise-injection</td>
<td>0.12</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>Proactive</td>
<td>Fibre-pull</td>
<td>14.97</td>
<td>0</td>
<td>4.97</td>
</tr>
<tr>
<td>Standard</td>
<td>Optical-switch (25ms)</td>
<td>11.61</td>
<td>11.16</td>
<td>11.32</td>
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<tr>
<td>Standard</td>
<td>Noise-injection</td>
<td>2852</td>
<td>2602</td>
<td>2727</td>
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<tr>
<td>Standard</td>
<td>Fibre-pull</td>
<td>83.43</td>
<td>13.49</td>
<td>37.63</td>
</tr>
</tbody>
</table>

Noise injection 0.1 ~ 1dB / 1000ms
Core DWDM Architectures & Operations

"Alien Wavelengths" & the Integration of WDM Optics on Client Equipment

One of the most interesting changes in the DWDM market over the past three years has been the development and positioning of architectures and solutions that support "alien wavelengths" — or the implementation of DWDM optics on clients of the DWDM network. The goal of this architecture is network simplicity and capex reduction, as it reduces a set of transponders in each network connection by placing DWDM optics on a router, switch, or multiservice provisioning platform (MSPP), which then interfaces passively to the DWDM network. The DWDM network, in the logical extreme of this architecture, is made up of passive mux/demux units, managed optical amplifiers, wavelength switches, and signal-conditioning equipment.
### Core DWDM Architectures & Operations

#### Value of Integrating DWDM Optics on Client Equipment

<table>
<thead>
<tr>
<th>DO YOU SEE VALUE IN INTEGRATING DWDM OPTICS ON ROUTERS AND SWITCHES TO REDUCE TRANSPONDERS IN A DWDM NETWORK?</th>
<th>NUMBER OF RESPONSES</th>
<th>PERCENT OF TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>54</td>
<td>62%</td>
</tr>
<tr>
<td>No</td>
<td>7</td>
<td>8%</td>
</tr>
<tr>
<td>Not sure</td>
<td>26</td>
<td>30%</td>
</tr>
<tr>
<td>Total</td>
<td>87</td>
<td></td>
</tr>
</tbody>
</table>

#### Concerns About Integrating DWDM Optics on Routers & Switches

<table>
<thead>
<tr>
<th>WHAT ARE YOUR CHIEF CONCERNS WHEN CONSIDERING INTEGRATING DWDM OPTICS ON ROUTERS AND SWITCHES?</th>
<th>NUMBER OF RESPONSES</th>
<th>PERCENT OF TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor/limited interoperability with DWDM system management</td>
<td>11</td>
<td>13%</td>
</tr>
<tr>
<td>Adds complexity to wavelength planning and management</td>
<td>28</td>
<td>33%</td>
</tr>
<tr>
<td>Loss of end-end control/management plane information and control</td>
<td>13</td>
<td>15%</td>
</tr>
<tr>
<td>Inferior support from router/switch vendors for DWDM transport</td>
<td>15</td>
<td>17%</td>
</tr>
<tr>
<td>No opinion/Don't know</td>
<td>19</td>
<td>22%</td>
</tr>
<tr>
<td>Total</td>
<td>86</td>
<td></td>
</tr>
</tbody>
</table>
IPoDWDM Supports 2 network management models

1. Segmented Management:
   • Retain existing operational model for certain SPs
   • Respect boundaries between IP/Transport groups

2. Integrated management:
   – End to end provisioning
   – Better trouble shooting
   – 1 mgmt system, 1 DB
   – Unified look & feel
   ✓ Lower OPEX
The Virtual Transponder (VTXP) Concept

- Virtual transponder protocol
  - Secure session between Router and WDM NE
  - Supports full FCAPS for WDM i/f
  - XML based

- The WDM NE converts VTXP info to its legacy information model to the EMS
  - Router reflected as a transponder shelf
  - WDM i/f reflected as a transponder

- No change to NMS/OSS
<table>
<thead>
<tr>
<th></th>
<th>Typical IP + DWDM</th>
<th>IPoDWDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic addition</td>
<td>Labour intensive</td>
<td>Zero touch (mostly)</td>
</tr>
<tr>
<td>L0-L3 coordination</td>
<td>Labour intensive: lots of processes</td>
<td>Seamlessly achieved via control plane</td>
</tr>
<tr>
<td>Availability</td>
<td>Lower – added OEO</td>
<td>Higher – minimum OEO</td>
</tr>
<tr>
<td></td>
<td>Lower – all outages are traffic affecting</td>
<td>Higher – slow outages are hitless</td>
</tr>
<tr>
<td></td>
<td>Lower – uncoordinated SRLGs</td>
<td>Higher – SRLGs are in sync</td>
</tr>
<tr>
<td>Management</td>
<td>Separate IP and DWDM management systems</td>
<td>Separate or integrated management, NLAC</td>
</tr>
<tr>
<td>Space and Power consumption</td>
<td>Sub-optimal</td>
<td>Optimal</td>
</tr>
</tbody>
</table>
Summary

- Traffic growth requires more focus on IP routers and DWDM technology
- Other services must still be supported but the network is not optimized around them
- IPoDWDM provides the required innovation to save CAPEX, OPEX and reduce power for the network
- Today’s features are only the beginning. We are committed to evolve the solution to a new level that is unachievable w/o integration
- Main challenges are non-technical. If you see the value, you can make it happen
Q and A
WDM PHY: Cost-Effective 10GE DWDM

- 10GE LANPHY payload over G.709 payload (over-clocked)
- OAM&P based G.709 Standard (SDH-like)
- FEC enabled transmission G.709 Standard modes, and Enhanced-FEC >1500 km

ITU standard references:
- G.709
  - Overclocking: G.sup43, sub-clause 7.1
  - Enhanced FEC: G.975.1 Appendix I.7

km of Reach (in a typical WDM system)
Network Architecture
First 40G IPoDWDM Network in the World

- The Comcast National Network is Currently:
  - Largest IPoDWDM Deployment in the World
  - Largest 40G DWDM Deployment in the World

Additional 40G “Express” Links not Shown

Key:
- 1 or more 40-G core links
- CRS-1 Router w/ 40G Integrated Optics

Additional 40G “Express” Links not Shown
IPoDWDM Interface Evolution

<table>
<thead>
<tr>
<th>Cost / complexity</th>
<th>2000km</th>
<th>1000km</th>
<th>300km</th>
<th>~50km</th>
<th>~1000km</th>
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</thead>
<tbody>
<tr>
<td>Good fiber (post 1995)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Old fiber (high PMD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **High**:
  - 100G
  - DPSK+ integrated TDC (G+)
  - Ext TDC
  - 40G ODB (G)

- **Low**: 10G OOK+EFEC (Rodan)

Ext PMDC
Where is 100Gig

- Cisco is working closely with IEEE and ITU
- Cisco is also working in Parallel on a final product, not waiting for entire standard
- IEEE focused on 40Gig E and 100Gig E SR
  Cisco will also implement WDMPHY
- Target FCS 1HCY10
Segmented Control Plane

L0 topology visibility (OSPF database)

RP/0/RP0/CPU0:MiniRex#sh ospf vrf optical database

OSPF Router with ID (10.10.10.10) (Process ID 1)

Summary ASB Link States (Area 0)

<table>
<thead>
<tr>
<th>Link ID</th>
<th>ADV Router</th>
<th>Age</th>
<th>Seq#</th>
<th>Checksum</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.85.85.200</td>
<td>10.85.85.229</td>
<td>182</td>
<td>0x80000006</td>
<td>0x00027e</td>
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<tr>
<td>10.85.85.200</td>
<td>10.85.85.238</td>
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<td>10.85.85.238</td>
<td>177</td>
<td>0x8000000b</td>
<td>0x0083e</td>
</tr>
</tbody>
</table>

Control plane debugging (Ping)

RP/0/RP0/CPU0:MiniRex#ping vrf optical 10.85.85.200
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.85.85.200, timeout is 2 seconds:
!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/4 ms

L3 IGP

Router 10 DWDM nodes Router

Control plane debugging (Ping)
Control Plane Futures
Sharing L0 SRLGs w L3

1. Provision L0 SRLGs into DWDM nodes & discover them via L0 IGP
2. Discover SRLGs per link in L0 network
3. Aggregate SRLG info & advertise SRLGs in the L3 IGP
4. Periodically check if SRLGs have changed
5. Use this info for applications such as FRR, alarms, and L3 planning
Control Plane Futures
Planned L0 Maintenance Driving Graceful L3 Shutdown

1. User informs L0 network of a span/NE that needs to be maintained
2. “Hitless” Fwd Maint Indicator (FMI) sent to end points of lightpaths traversing optical NE requiring maintenance
3. FMI signal can be propagated to router, invoking proactive protection for all traffic using these lightpaths
4. Router can alarm user or send back Nack if it cannot handle this link going down at this time
5. Eliminates need to coordinate maint activity between L0 & L3
Control Plane Futures
Optical Auto-Bandwidth

- Router measures utilization for L2 link bundles (LAG)
- If utilization is high – request the set up of another wavelength from L0 and add it to the link bundle
- Original topology retained to avoid convergence issues – channel add/remove within existing link bundles
Segmented Management via CTC
Managing the Transport Layer incl DWDM i/fs in MSTP R9.0

- CTC shows CRS nodes w WDM i/fs as well as MSTP nodes
- CTC can set up A-Z connections (incl DWDM controller)
- CTC displays “show DWDM controller” results and alarms
Segmented Management via CTC
Show Router DWDM Controller: Port status
Careful DWDM layer design with the future in mind

- Future proof grid
  - Must accommodate a variety of possible future modulation formats for 100Gbps and beyond
  - Pushing for Flex Spectrum instead of a fixed grid
  - In the meantime sticking to 100GHz grid is safer

50GHz grid (80 ch) is OK for 40G

Will it be optimized for 100G?

Best solution: Flex Spectrum

100GHz is a safe bet near term
LMP and alarm correlation details

Goal: ensure only one system must act upon a failure

Value:
- Downstream indicator allows router alarm to be downgraded → avoid L3 craft action
- Upstream indicator allows transport alarm to be downgraded → avoid L0 craft action