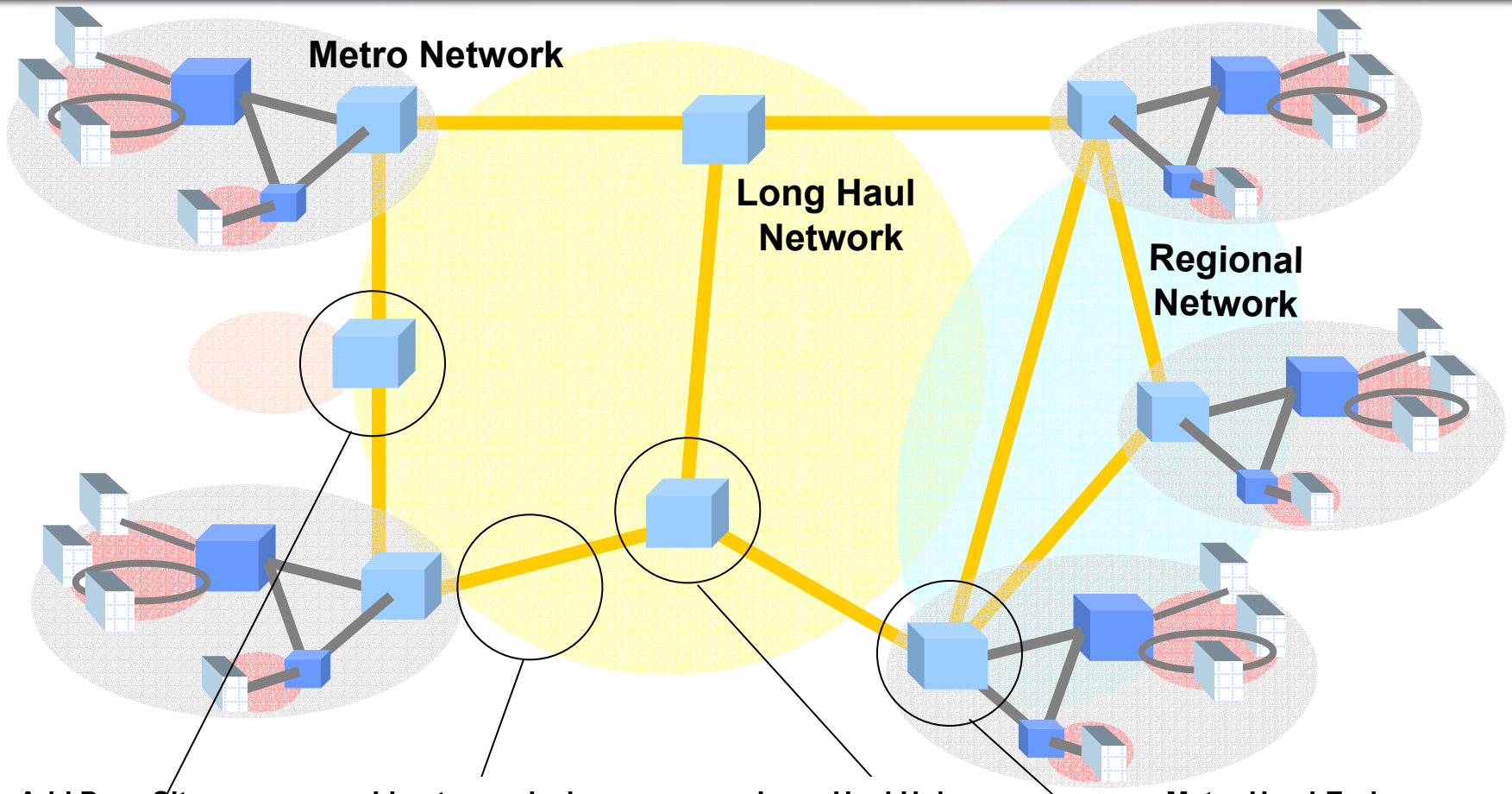
Towards the Agile Optical Network

April 13, 2004

Agenda

1. High-Performance Network Evolution
   - Optical Network Architectures
   - Networks for Scientific Applications
2. Emerging Technologies
   - Optical Technology Directions
3. Interoperability Challenges
   - Control Plane Technologies

The Emerging Optical Network



Add Drop Site
- Majority of traffic pass through
- Some amount of traffic adds/drops

Line transmission
- High capacity (bits,λ) per fiber
- Reach
- Line rate integrity

Long Haul Hub
- Intersection of multiple routes
- Switch traffic transparently
- Protection and restoration
- Regeneration if needed

Metro Head-End
- Intersects multiple routes
- Switches and grooms local traffic
- Protection and restoration
- Interfaces to service NE's

Networks for Science

Needs	Solutions
• **Very high bandwidth pipes** – Scale: Campus to International – Diverse service types	→ • **Wavelengths to the User** – Aggregate traffic onto wavelengths as near as possible to user – Transparently switch wavelengths in the Metro/Regional
• **Agility and Dynamism** – Multi-site groups, highly collaborative – Service type/endpoint agility – Rapid provisioning, close to the end-user community	→ • **Unified Control Plane** – Leverage existing IP technologies – Distributed intelligence, in the network – Control specific transport capabilities, via GMPLS
• **Internetworking** – Migrate from, integrate with packet infrastructure – Support existing optical services within standardized DWDM	→ • **Standardized Data Plane** – G.709, other standards – Incorporate external (“alien”) ITU-T grid wavelengths

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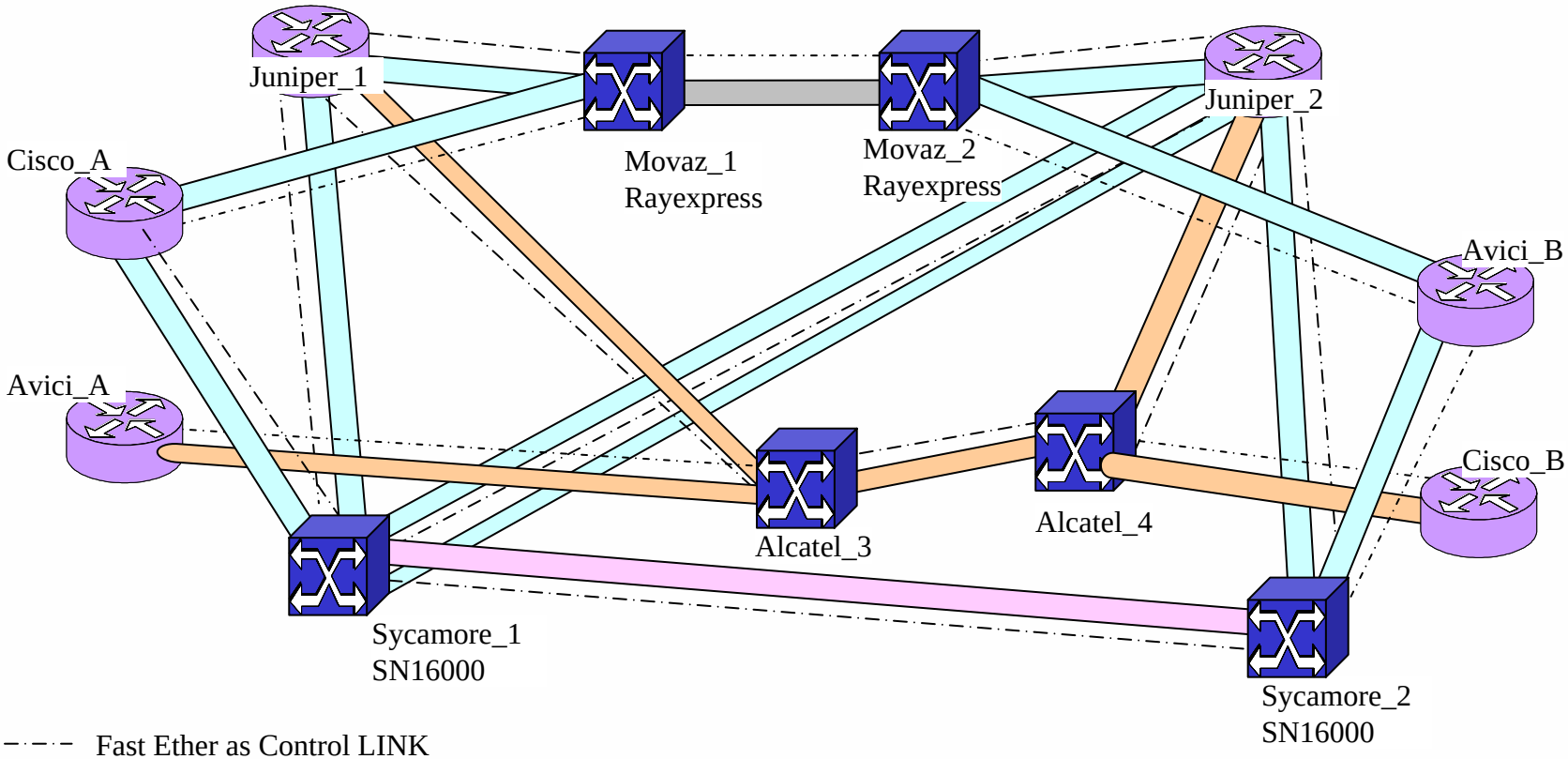
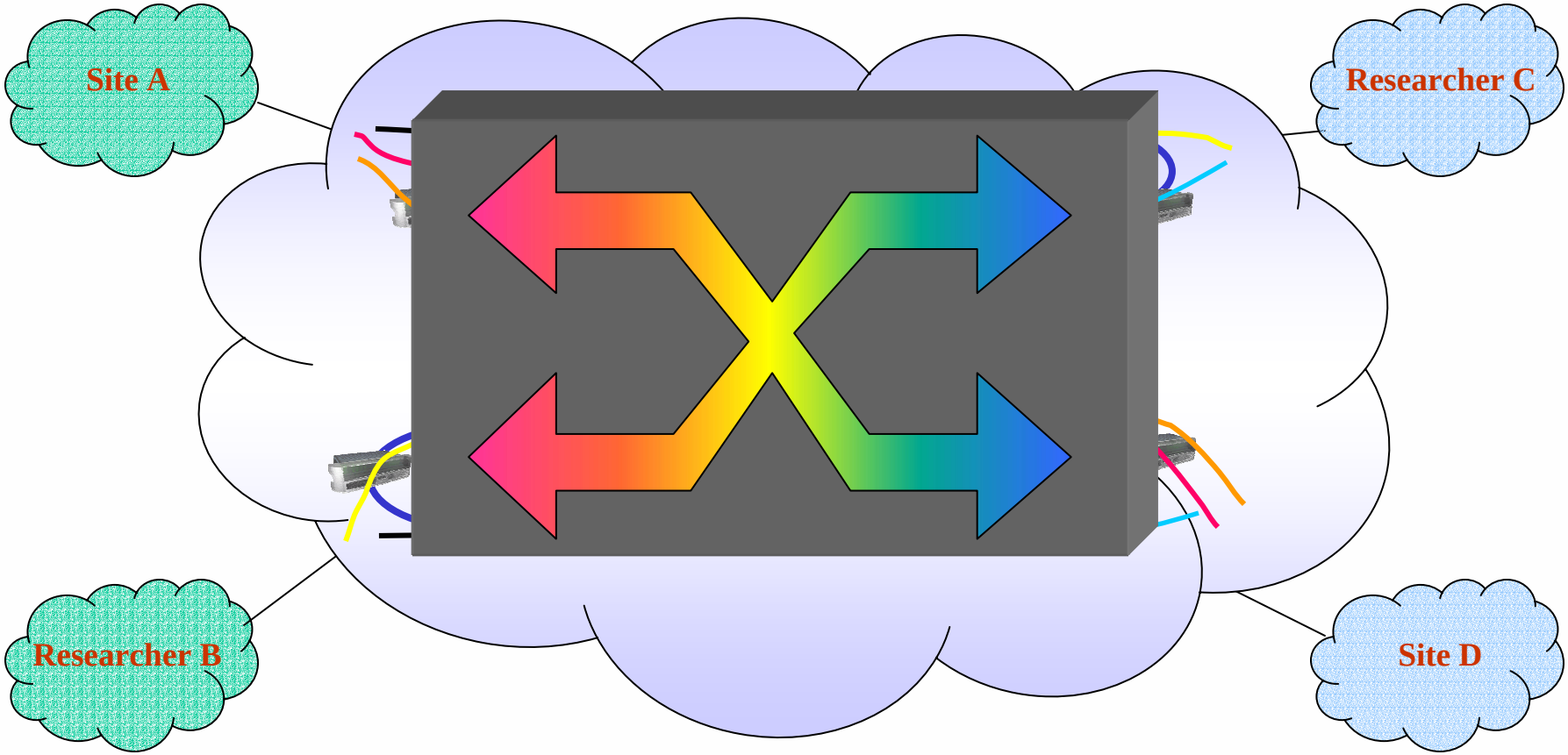
Interoperability Challenges



- **Challenge: How best to serve scientific applications?**

User Community View

High-performance, dedicated connections over multiple transport clouds



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Agility

Types

- **Endpoint Agility**
  - Establish high-performance connections between two or more endpoints, on-demand
- **Wavelength Agility**
  - A finite inventory of wavelengths
  - Select/change wavelength used to carry service between endpoints
- **Provisioning Agility**
  - High-bandwidth services often cross administrative boundaries
  - Establish services rapidly, securely, on-demand

Solutions

- **Scalable Switching**
  - Ability to switch wavelength services, in both Metro and Regional
  - Need both low initial, low per/λ cost
- **Tunability/Plugability**
  - Select/change service-facing optics using standard XFP/SFP interfaces
  - Select/change network-facing optics through tunable devices
- **Standardized Control Plane**
  - Move to higher levels of provisioning functionality: “services” rather than “circuit packs”
  - GMPLS standards drive inter-cloud interoperability

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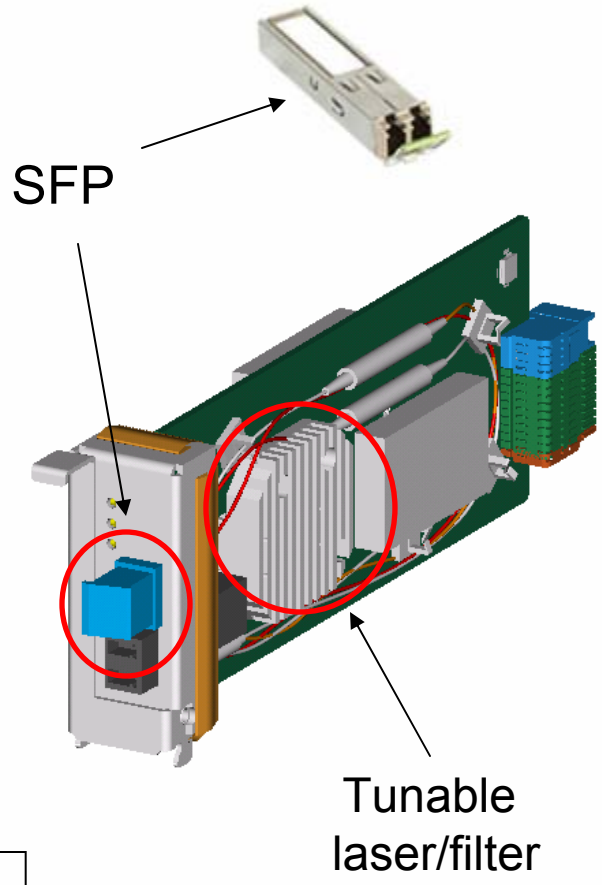
Tunability/Plugability

- **Single Form Pluggable (SFP/XFP)**
  - Single circuit pack
  - Multiple client service types
    - 980nm, 1310nm, 1550nm
    - Short, medium, long reach
  - Reduces sparing, inventory, costs

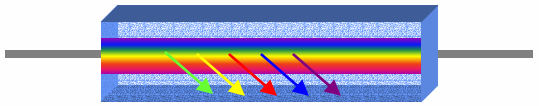
- **Tunable Lasers/Filters**
  - Again, single circuit pack
  - Line-side wavelength tunable
    - Any λ on 40 λ ITU grid
  - Select λ at service creation time



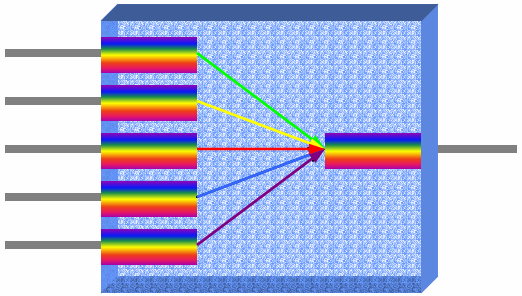
Result: wavelength agility

Scalable Wavelength Switching

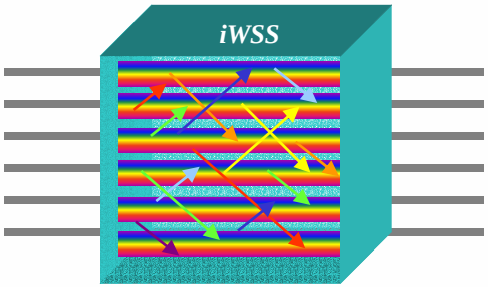
- **Single port 1x1x40 switch**
  - MEMS technology, HV/LV drive ASICs originally developed for high-density iWSS
  - Application: DCE in ROADM



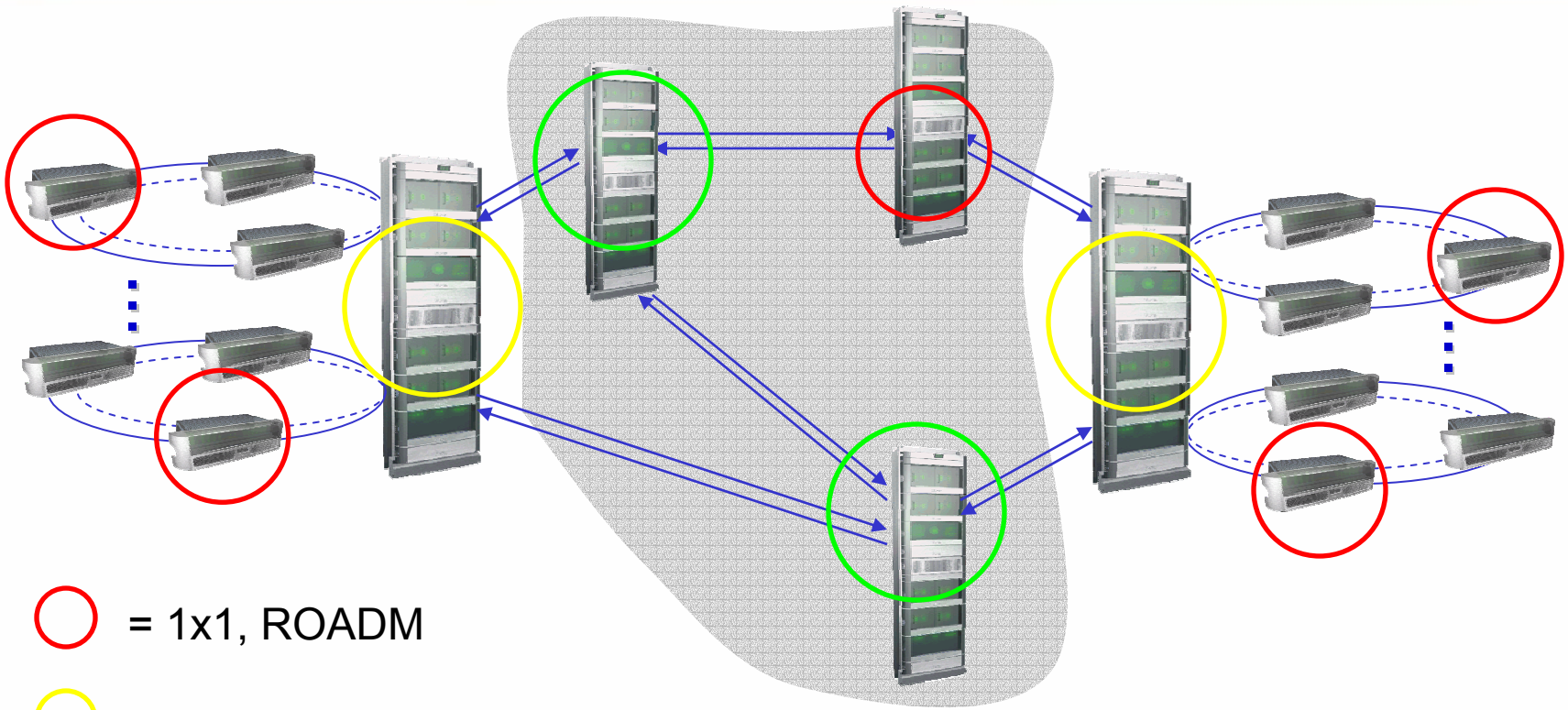
- **Multi-port 1x5x40 switch**
  - Expanded port count, in one direction only
  - Application: transparent ring interconnect



- **Monolithic 10x10x40 iWSS**
  - Highest density, lowest per-wave cost; prototypes deployed



Scalable Switching



= 1x1, ROADM

= 1xN, Ring Interconnect

= NxN, Mesh, Multilink

Result: endpoint agility, transparent interconnect at reasonable cost

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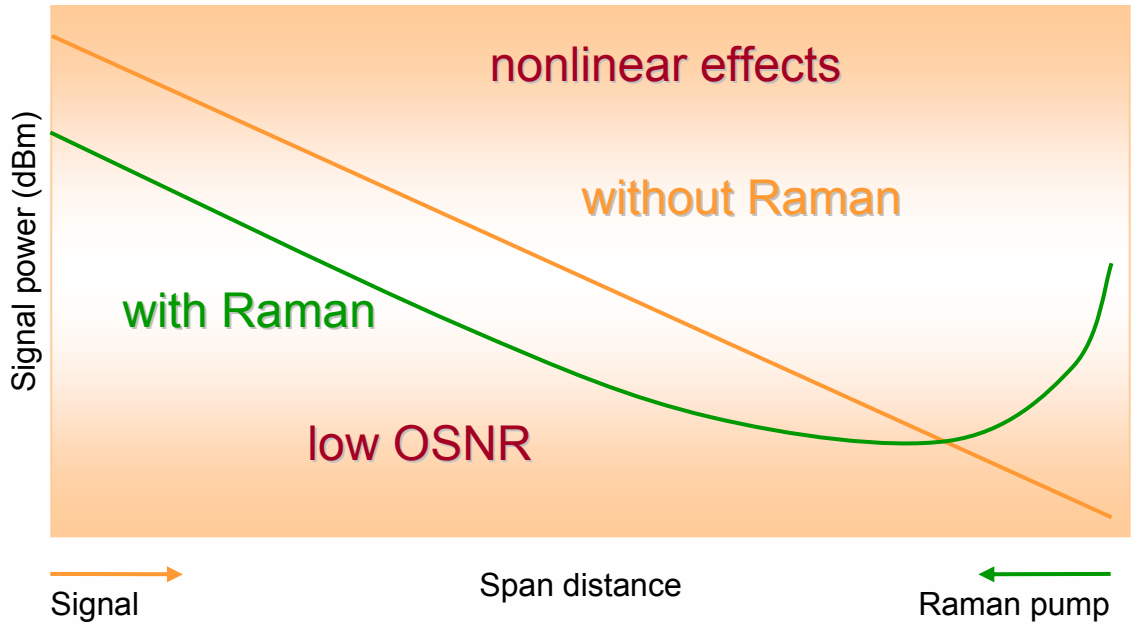
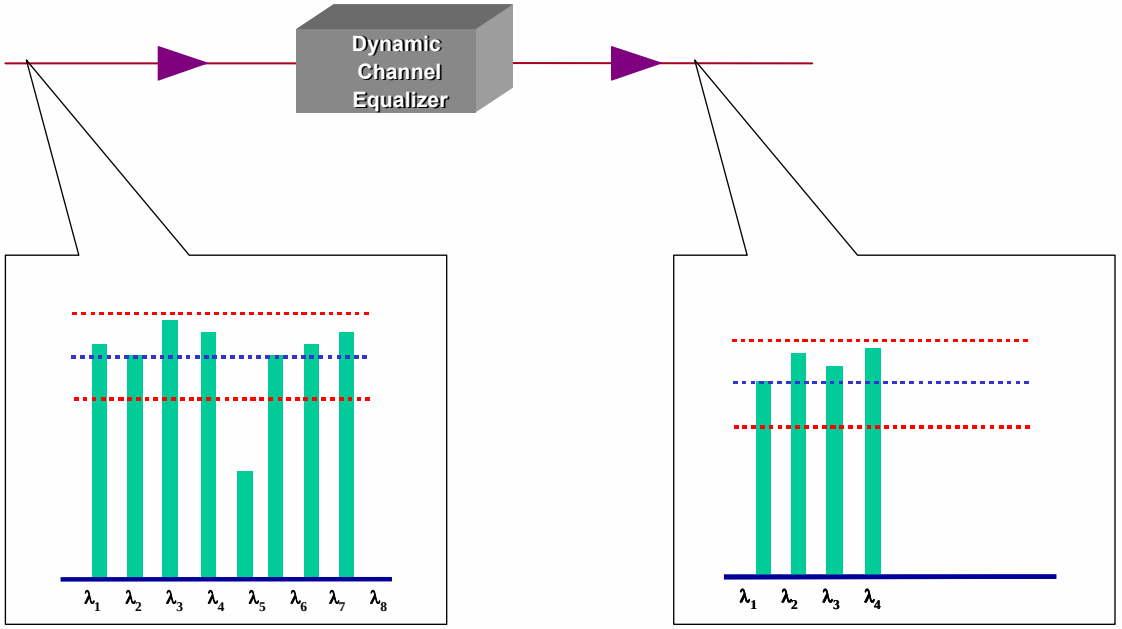
Raman Amplification



- Reduces need for in-line amplifiers (ILA) → Lower network cost
- Maintains constant signal power over span → Higher reach
- Avoids low signal at end of span → Better OSNR
- Allows lower power at start of span → Fewer impairments

Result: expand reach/penetration of optical services

Adaptive Monitoring



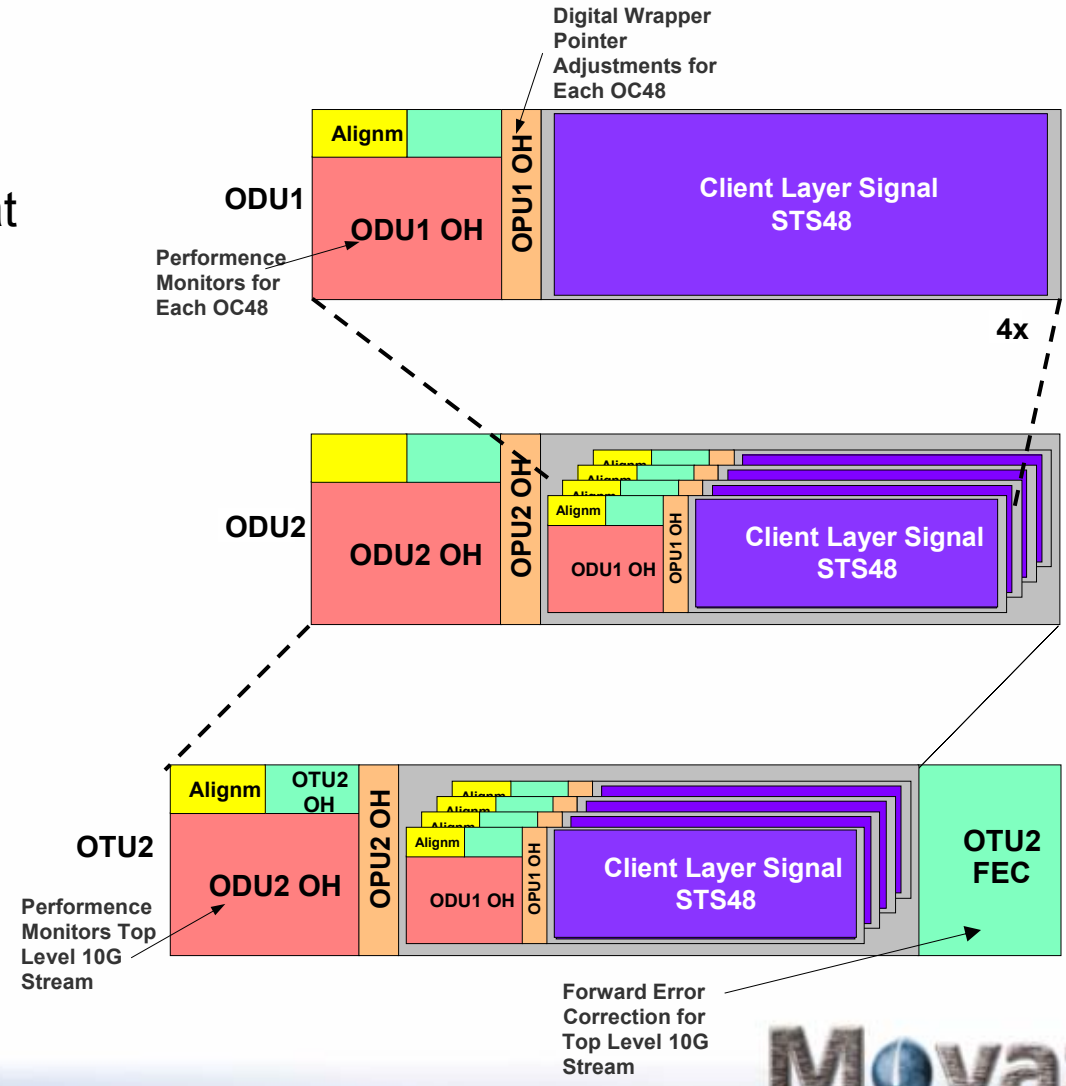
- Network Element constantly monitors per-λ input power
- MEMS-based DCE used to equalize output levels
- As new λ are added/dropped/passed thru, power levels automatically adjust

Result: network adapts automatically

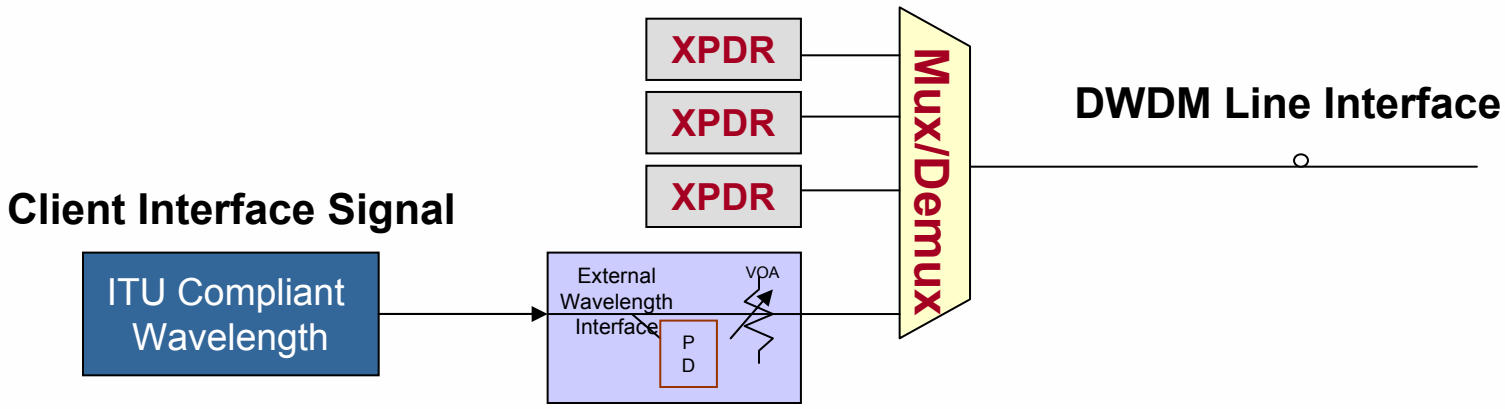
Digital Wrapper Multiplexing

- **Line-side integration**
  - Standardized data plane
  - Single encapsulation format
  - Advanced capabilities
    - FEC
    - PMs
  - G.709 ITU-T standard

- **Result:**
  - Identical capabilities across diverse payloads
  - improved monitoring
  - Multi-vendor interop



External Wavelengths



Option 1: External λ Interface

- Requires Well Defined ITU Compliant Signal
- Less control on wavelength transmit power
- Limited PMs

Option 2: XPDR Interface

- Performs Retiming
- Wavelength independent (1310)
- Optical PMs
- Fault Isolation/Diagnostics
- Increased Expense

Result: integrate legacy λ

Emerging Technologies

- **Tunability/Plugability**
  - Standardized SFP/XPF tributary optics; lower costs, improve sparing
  - Tunable filters, lasers, DCMs; wavelength agility
- **Scalable Wavelength-Selective Switching**
  - Building block approach, entry at reduced cost
  - Endpoint agility in Metro, Regional areas
- **Amplification and Monitoring**
  - Raman amplifiers: longer reach, avoid regeneration in Metro/Regional
  - Integrated per-lambda monitoring/equalization; cheaper components
- **Legacy, Inter-cloud integration**
  - Digital Wrapper; unified data plane encapsulation
    - Enables consistent monitoring, error correction, multi-vendor
  - External (“Alien”) Wavelengths; ITU-T grid integration
    - Integrate legacy/proprietary wavelengths with standard DWDM

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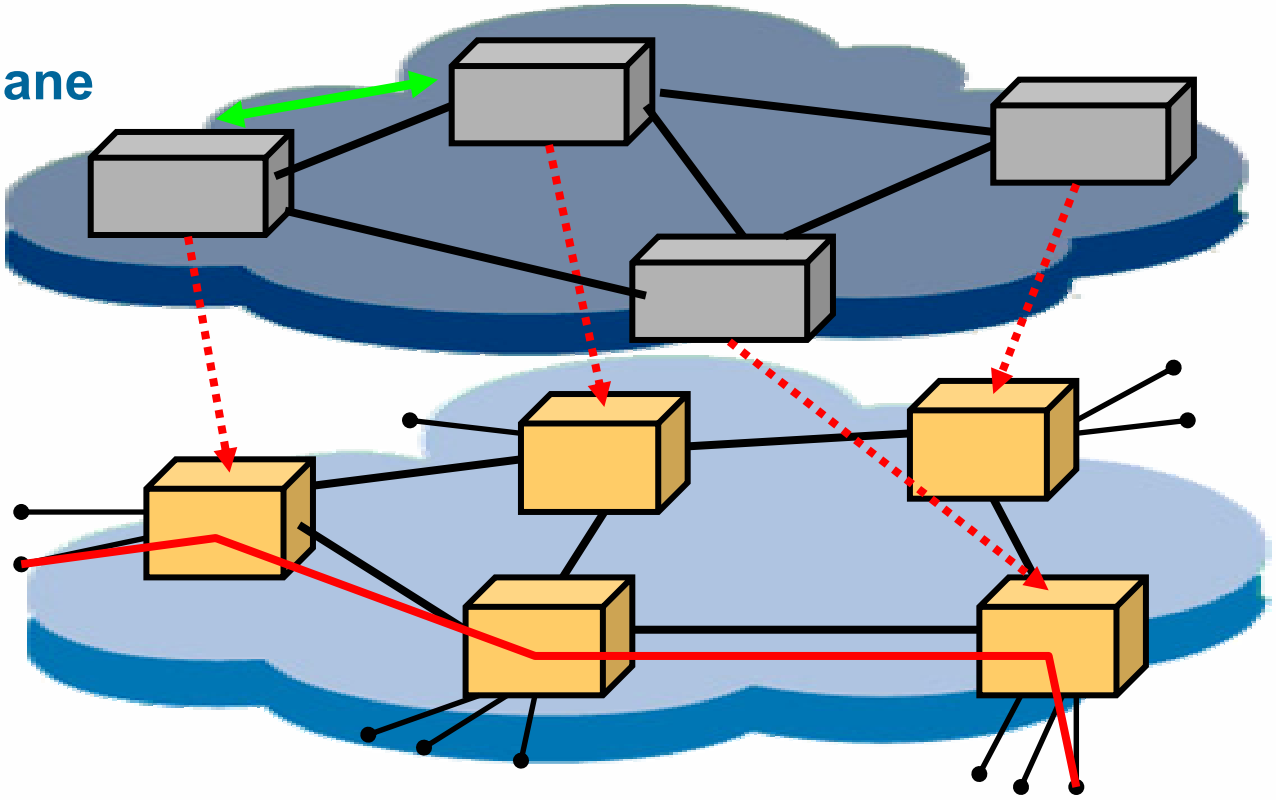
3. **Interoperability Challenges**
   - **Control Plane Technologies**

Unified Control Plane

- Provision end-to-end services and circuits dynamically
- Intelligence is embedded in the network

GMPLS Control Plane
RSVP-TE, CR-LDP
OSPF, IS-IS



Data Plane
MPLS, SONET/SDH,
Ports, WDM, ATM

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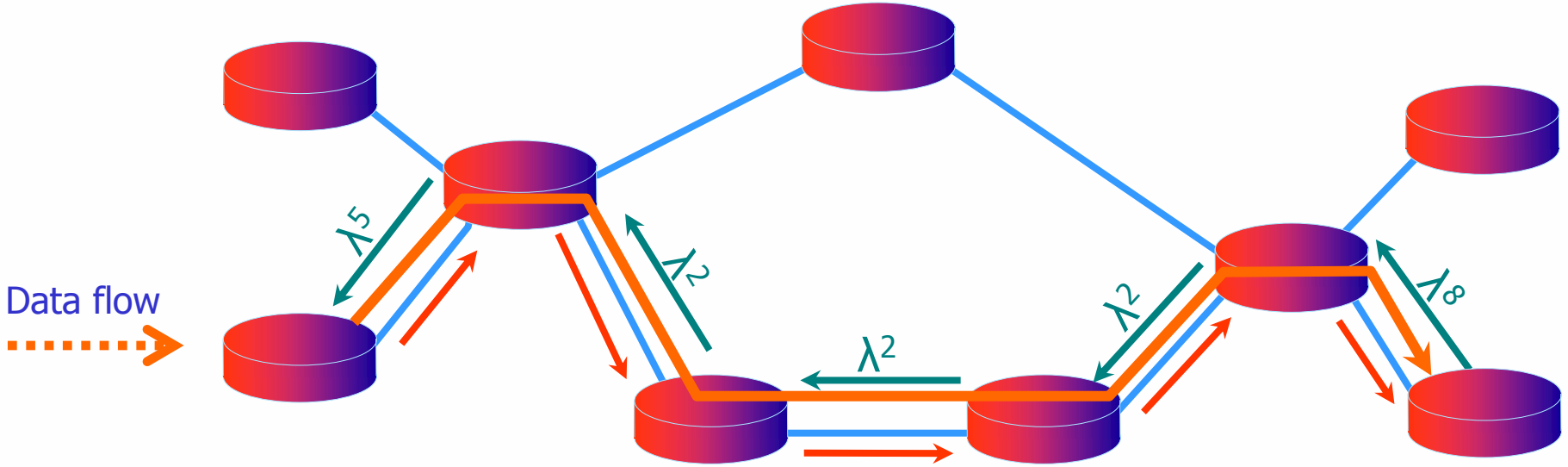
GMPLS Controlled Path

- **Reuse of MPLS and IP Control**



  - Ingress initiates light path setup
  - Request propagated to egress
  - Egress responds with lambda
  - Response propagated upstream to ingress

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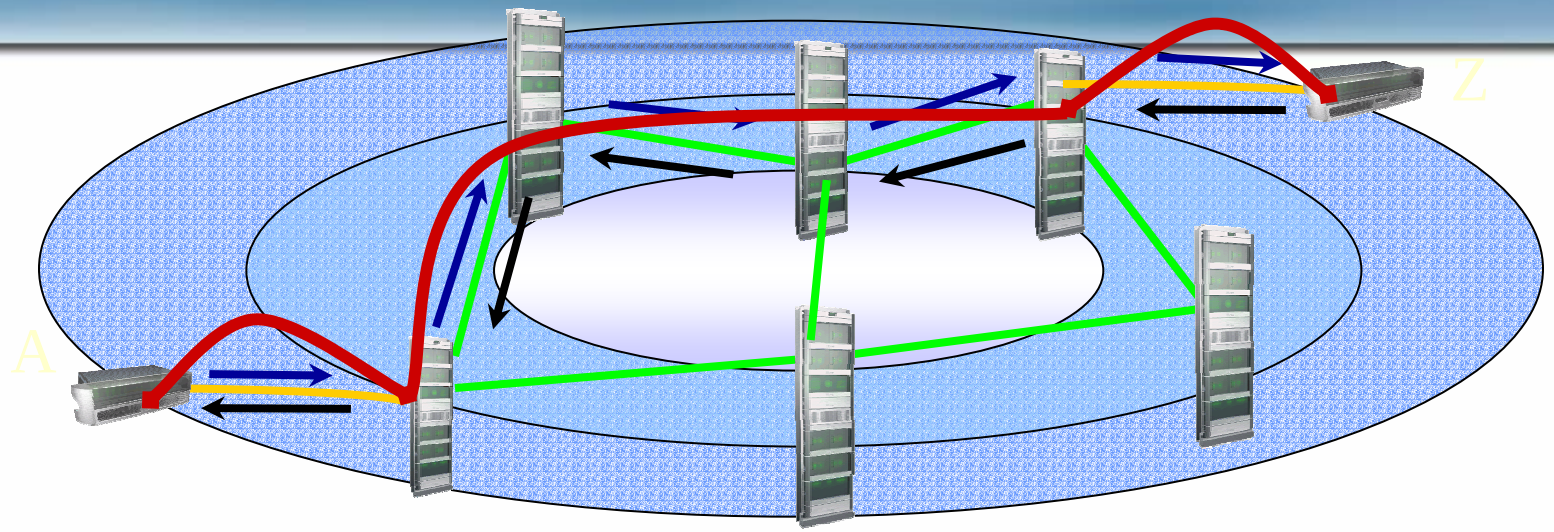
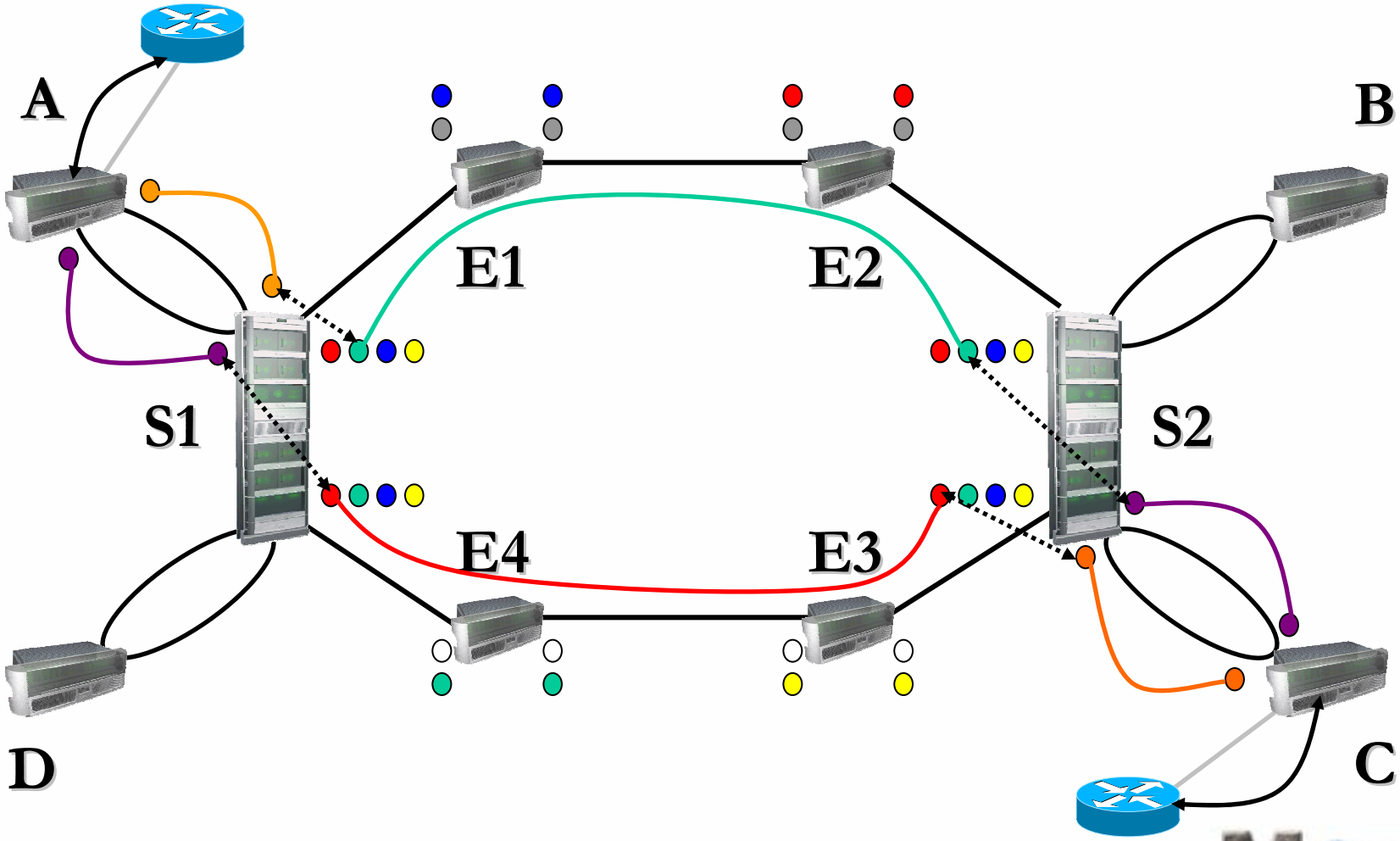
GMPLS Functions



Routing	Path Computation	Signaling
Provides topology and resource availability information to all nodes	Selects paths within the network (subject to constraints, including optical impairments)	Establishes optical services dynamically in real-time

Multi-Network Provisioning



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Provision A to C, Manual

At A, execute:

1. Set SIM port service type or rate
2. Set SIM port customer name
3. Set destination SIM port
4. Enable SIM port
5. Set SIM protection mode
6. Set SIM preferred plane
7. If "purple" XCVR is EAML, set datarate
8. Enable "purple" XCVR transmit laser
9. If "orange" XCVR is EAML, set datarate
10. Enable "orange" XCVR transmit laser

At S1, execute:

1. Set "orange" XCVR datarate
2. Set "orange" XCVR protection mode
3. Set "orange" XCVR preferred plane
4. Set "green" XCVR datarate
5. Set "green" XCVR protection mode
6. Set "green" XCVR preferred plane
7. Crossconnect "orange" to "green"
8. Crossconnect "green" to "orange"
9. Enable "orange" XCVR transmit laser
10. Enable "green" XCVR transmit laser
11. Set "purple" XCVR datarate
12. Set "purple" XCVR protection mode
13. Set "purple" XCVR preferred plane
14. Set "red" XCVR datarate
15. Set "red" XCVR protection mode
16. Set "red" XCVR preferred plane
17. Crossconnect "purple" to "red"
18. Crossconnect "red" to "purple"
19. Enable "purple" XCVR transmit laser
20. Enable "red" XCVR transmit laser

At S2, execute:

1. Set "green" XCVR datarate
2. Set "green" XCVR protection mode
3. Set "green" XCVR preferred plane
4. Set "purple" XCVR datarate
5. Set "purple" XCVR protection mode
6. Set "purple" XCVR preferred plane
7. Crossconnect "green" to "purple"
8. Crossconnect "purple" to "green"
9. Enable "green" XCVR transmit laser
10. Enable "purple" XCVR transmit laser
11. Set "red" XCVR datarate
12. Set "red" XCVR protection mode
13. Set "red" XCVR preferred plane
14. Set "orange" XCVR datarate
15. Set "orange" XCVR protection mode
16. Set "orange" XCVR preferred plane
17. Crossconnect "red" to "orange"
18. Crossconnect "orange" to "red"
19. Enable "red" XCVR transmit laser
20. Enable "orange" XCVR transmit laser

At C, execute:

1. Set SIM port service type or rate
2. Set SIM port customer name
3. Set destination SIM port
4. Enable SIM port
5. Set SIM protection mode
6. Set SIM preferred plane
7. If "purple" XCVR is EAML, set datarate
8. Enable "purple" XCVR transmit laser
9. If "orange" XCVR is EAML, set datarate
10. Enable "orange" XCVR transmit laser

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Provision A to C, Control Plane

At A, execute:

1. Set destination IP address to C
2. Set destination SIM card
3. Set source SIM card
4. Select SIM card port
5. Set SIM port service type or rate
6. Set SIM port customer name
7. Set destination SIM port
8. Commit service
9. DONE!

Summary

- **Networks for Science have special needs**
  - Big pipes, agility, multi-network provisioning
  - Wavelengths to the user, on-demand
- **Emerging optical technologies as enablers**
  - Managed wavelengths, leverage decreasing cost of DWDM
  - Migrating from Long-haul to Regional to Metro to Campus
- **Intelligent management**
  - Diverse transport technologies, must integrate
  - Interoperability, amongst vendors and across providers
- **Serve the User Community**

Thank you