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IP and Optical: Better Together?

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An SAIC Company

IP and optical networks:

how to build a network that handles IP traffic but that optimizes overall network performance and cost

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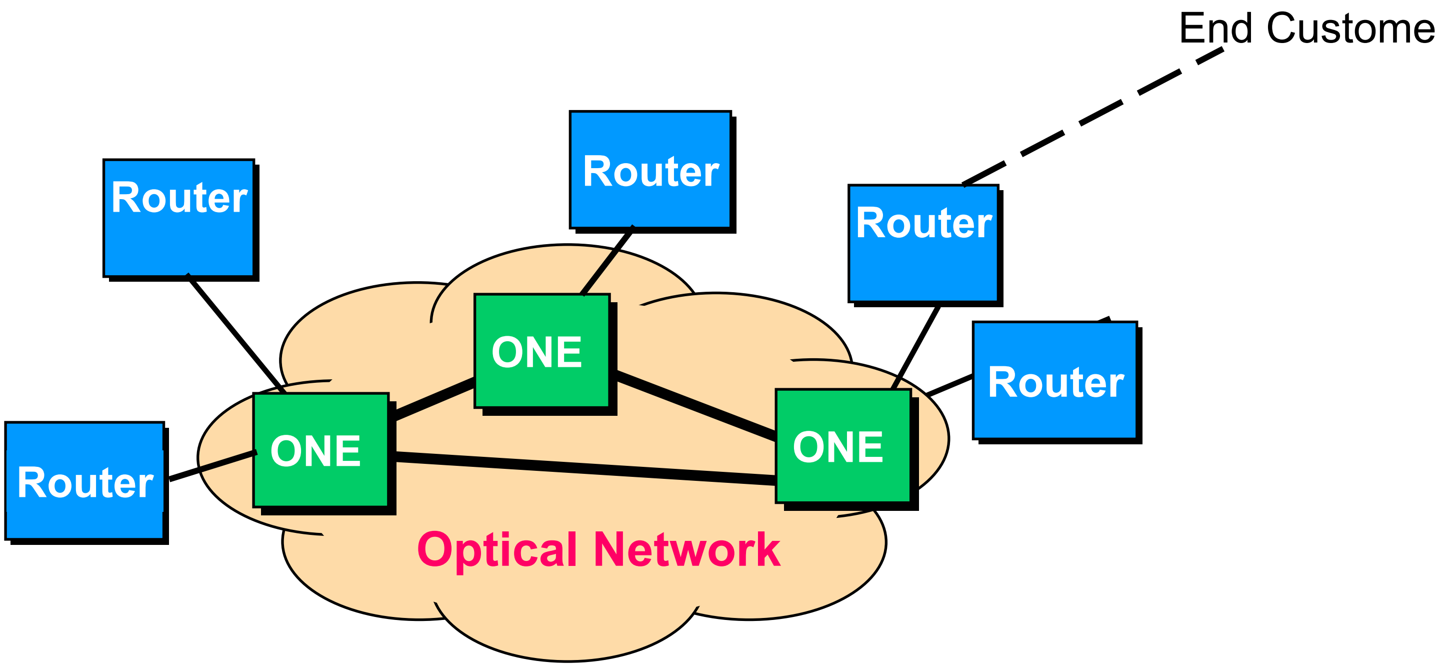
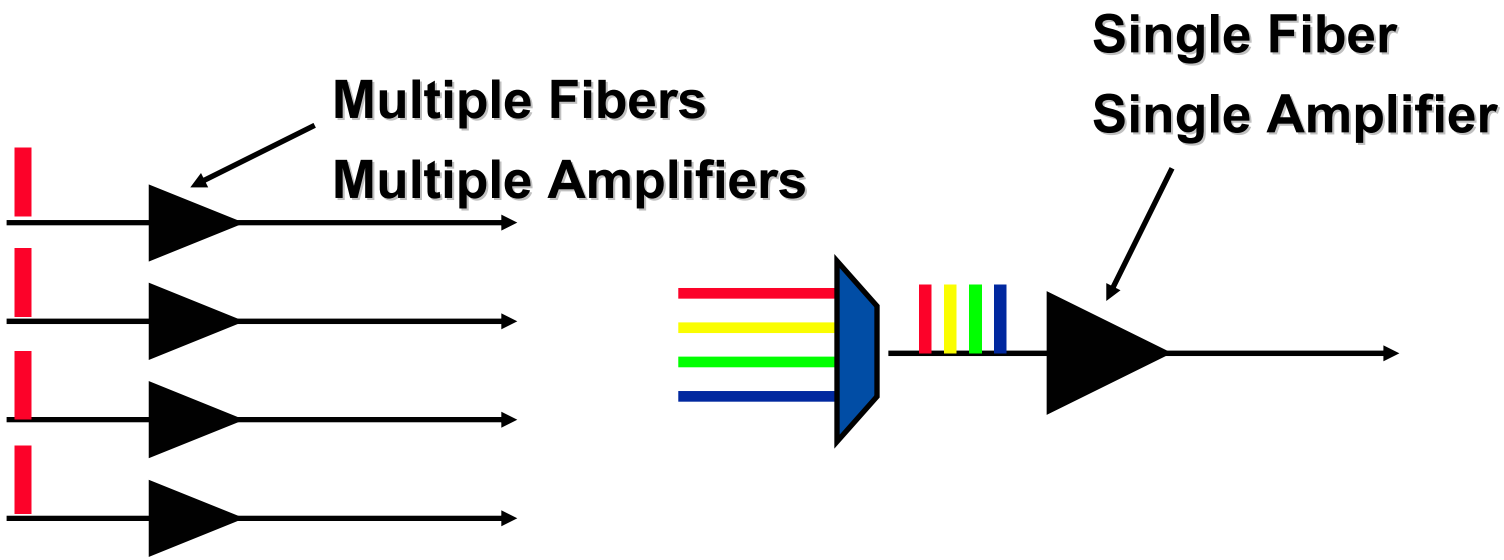
Outline

- Optical Networks 101
- What can optics do for the IP layer?
  - Transport
  - Restoration
  - Reduce the cost of routing IP traffic
  - Traffic engineering
- Paradigms for closer interworking
  - how far to go?

Basic Network: IP routers + Optical network elements



Optical Networks 101: Wavelength Division Multiplexing (WDM)



WDM = A Capacity Multiplier

Technology development has been driven by the need for bandwidth

Source of the traffic growth is the Internet

The Internet is still estimated to be growing at 100%/year

Networks need to grow in capacity by 32x in 5 years!

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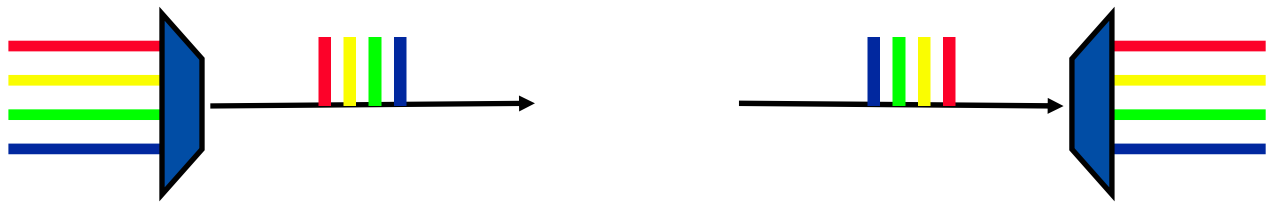
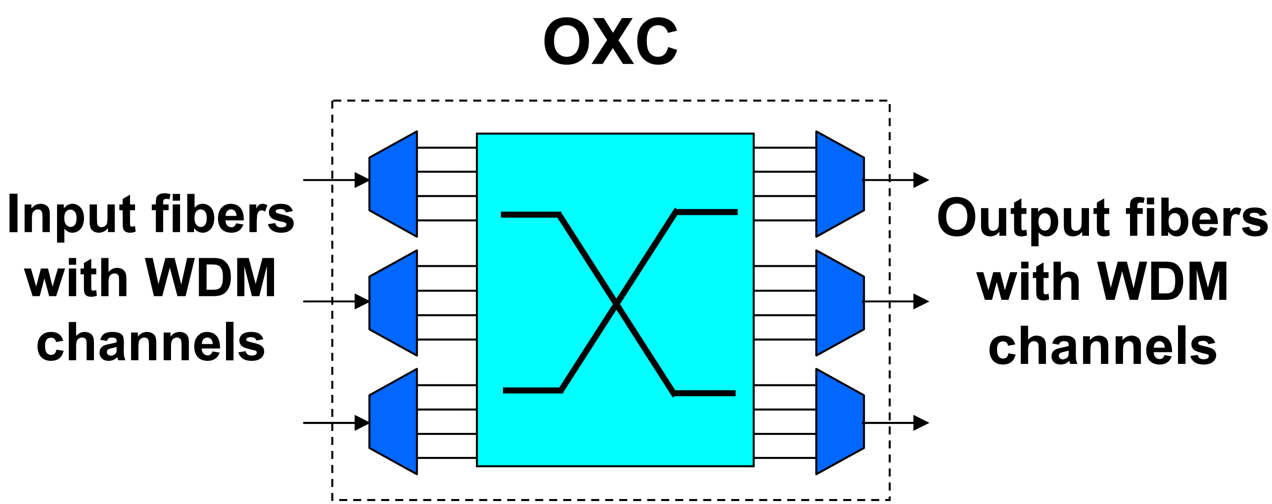
Optical Network Building Blocks: Point-to-Point Wavelength Multiplexing Systems



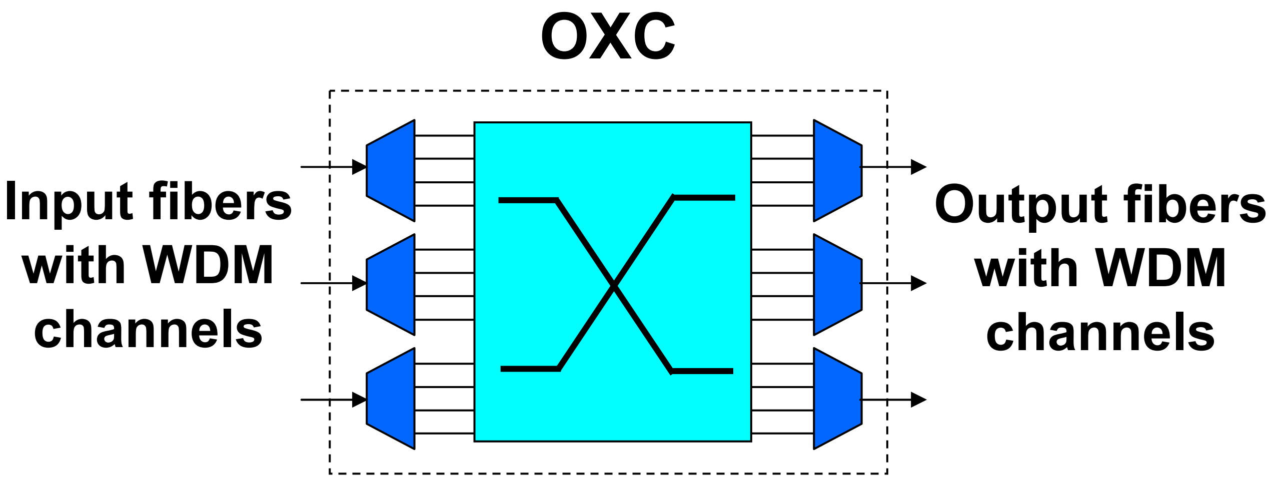
- **Multiplexing of as many as ~200 wavelengths on a fiber ("Dense WDM", or DWDM)**
- **Rates of 2.5 and 10 Gb/s; work on 40 Gb/s systems underway**
- **Significant deployment in long haul networks (largest aggregation of traffic, long distances)**
- **Products available from many manufacturers (Ciena, Nortel, Lucent,...)**
- **Optical layer fundamentally provides *transport* of IP packets**

Optical Network Building Blocks: Optical Cross-Connects (OXCs)



- OXC switches signals on input {wavelength$_i$, fiber$_k$} to output {wavelength$_m$, fiber$_n$}

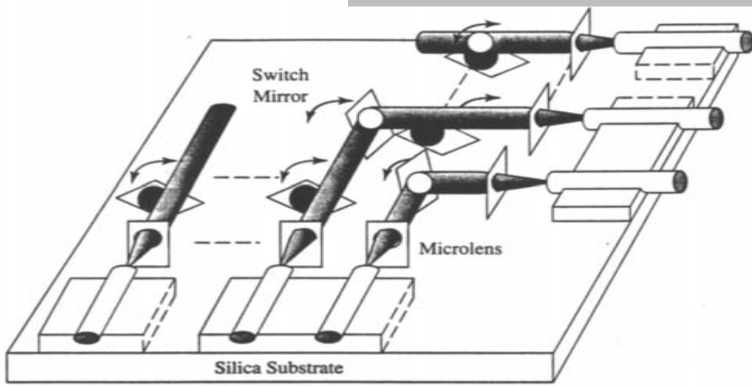
Optical Cross-Connects (OXCs)

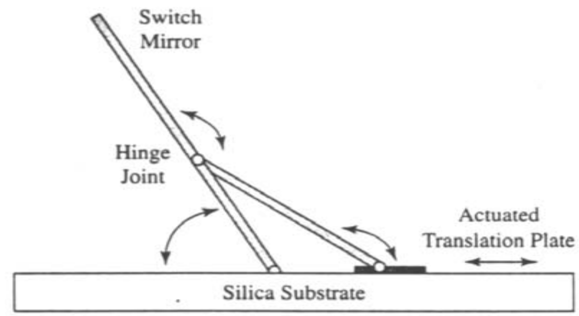


- ‘Opaque’: o-e, e-o, electronic switch fabric
- ‘Transparent’: o-o-o, optical switch fabric
- Hybrid, (o-e-o): optical switch fabric, o-e-o
- Hybrid: both opaque and transparent fabrics
- Tunable lasers + passive waveguide grating

Inside the Cross Connect: All Optical Switch Technologies: MEMS

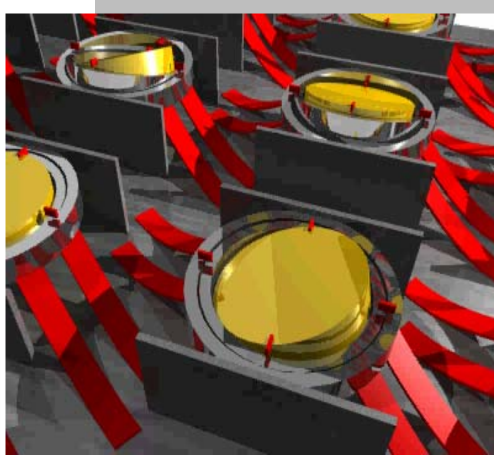
Schematic Drawings of a
Micro-machined Free-Space Matrix Switch
Source: Scanned from [9.Lin]



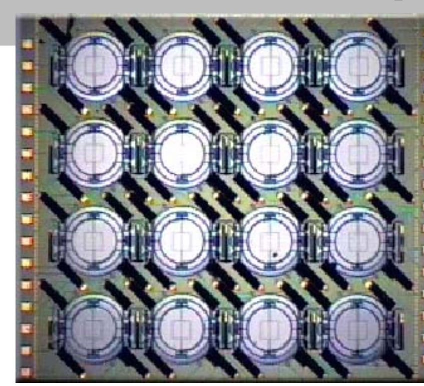


Detail of the Switch Mirrors

Lucent MicroStar™ MEMS Based Mirror Array Technology
Source: [Butt]



Optical X-C 2-axis Micromirror



4×4 array of 2-axis micromirrors

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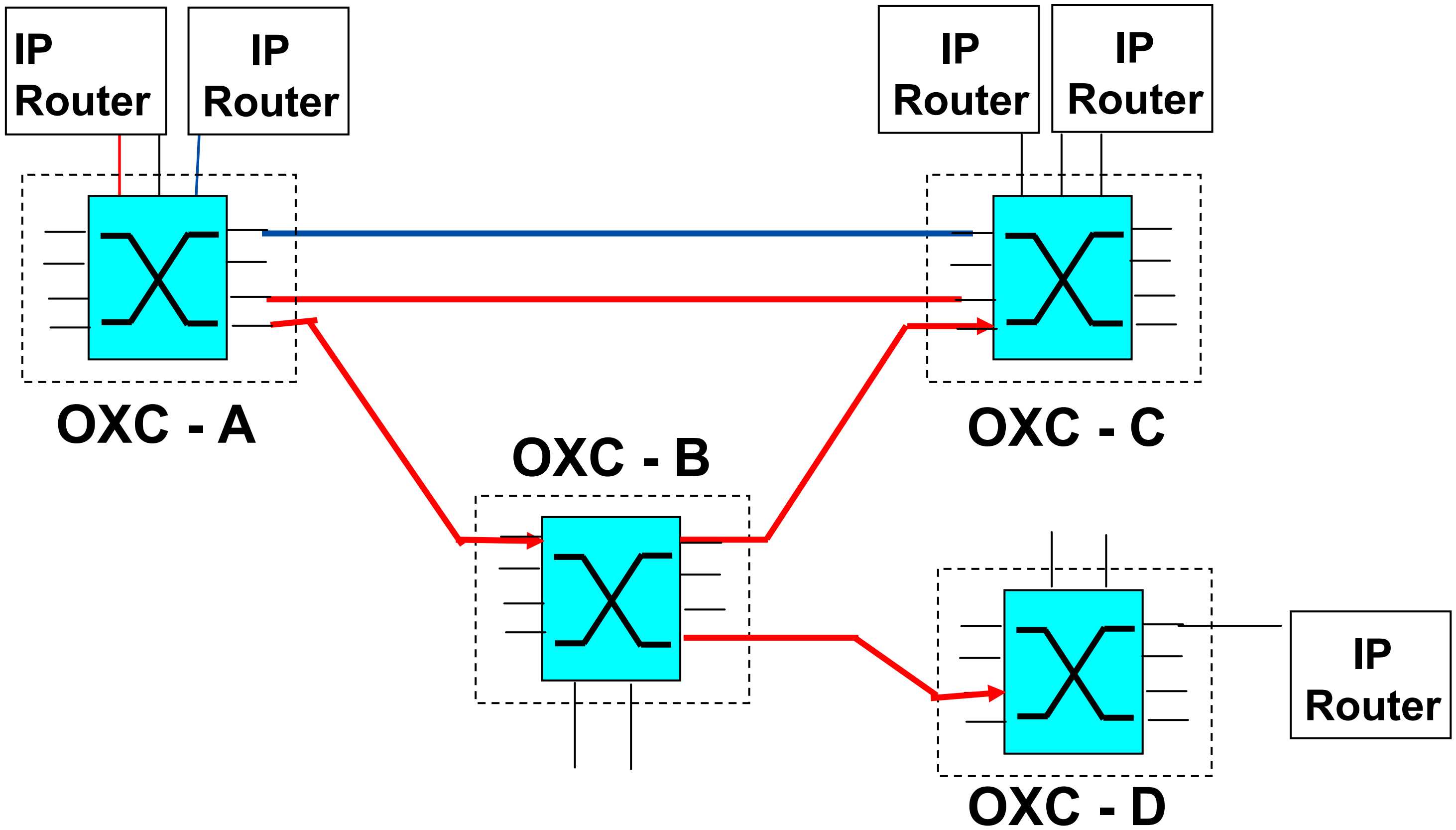
Important optical layer capability: reconfigurability



Crossconnects are reconfigurable:

- ***Can provide restoration capability***
- ***Provide connectivity between any two routers***

How useful is optical reconfigurability for an IP network?

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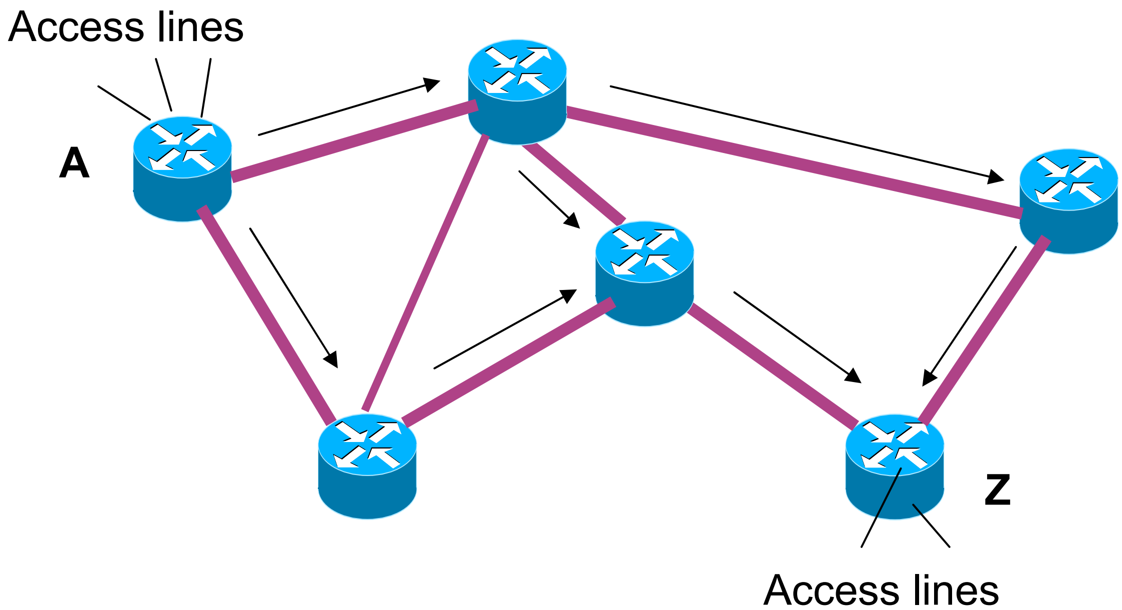
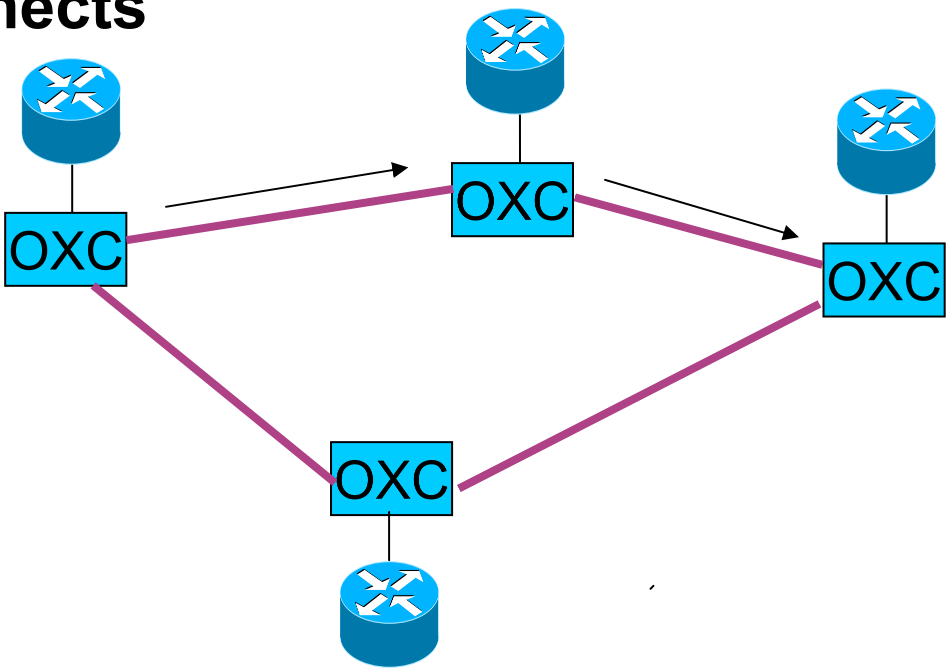
Architecture 1: Big Fat Routers and Big Fat Pipes



- All traffic flows through routers
- Optics just transports the data from one point to another
- IP layer can handle restoration
- Network is 'simple'

- But…..
  - more hops translates into more packet delays
  - each router has to deal with thru traffic as well as terminating traffic

Architecture 2: Smaller routers combined with optical crossconnects



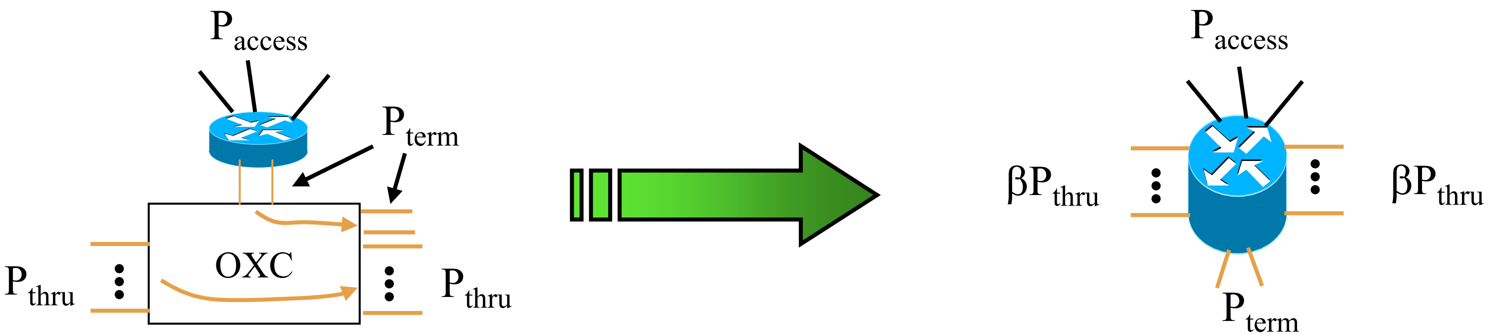
- Router interconnectivity through OXC's
- Only terminating traffic goes through routers
- Thru traffic carried on optical 'bypass'
- Restoration can be done at the optical layer
- Network can handle other types of traffic as well

•But: network has more NE's, and is more complicated

Performance/cost comparisons: Networks with and without OXC's

- Performance Considerations
  - IP Packet delays--# of hops
  - Restoration
  - traffic engineering--efficient use of network resources
  - Handling multiple types of services
- Cost Considerations
  - Number of network elements (equipment and operations costs)
  - Different types of ports (IP and OXC) and total port costs
  - Fiber costs and efficiency of fiber and λ usage
  - Static vs dynamic cost analysis

Cost Analysis: Compare the two architectures



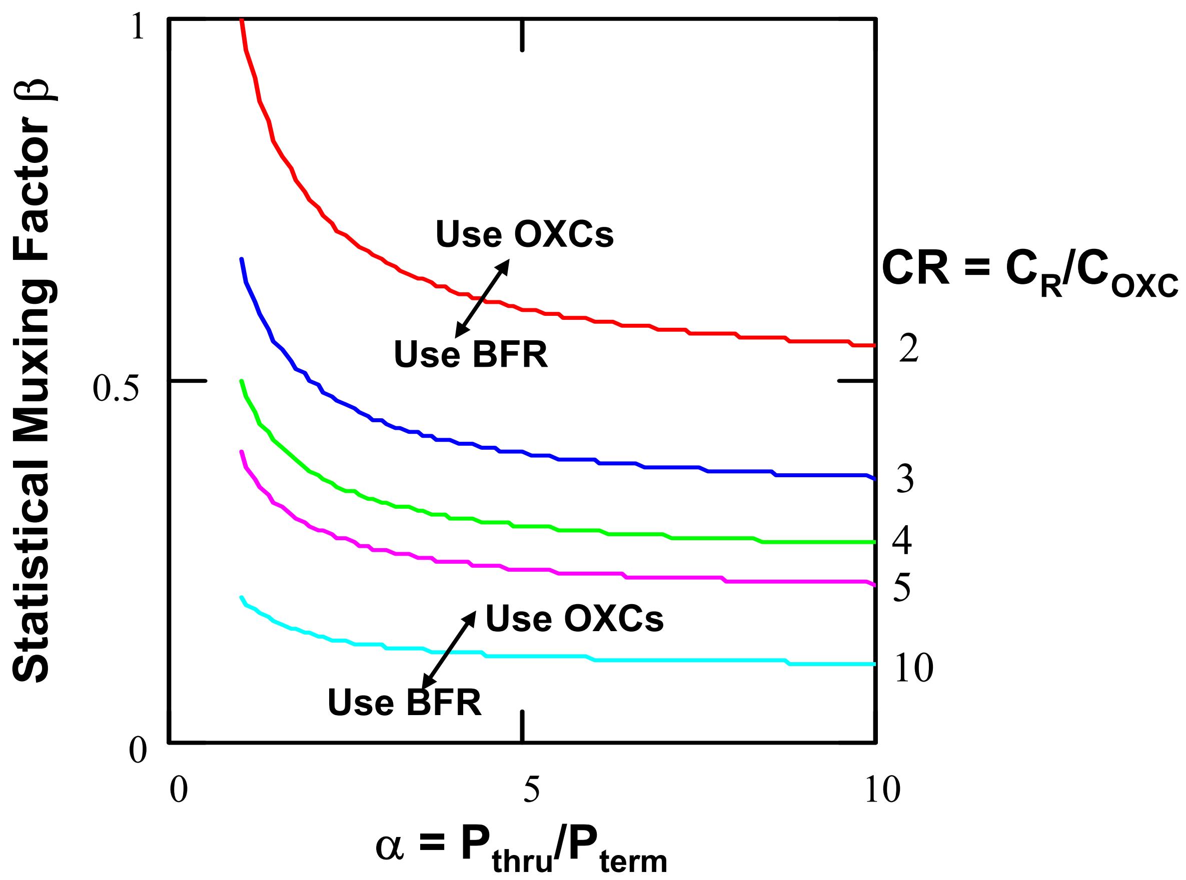
Total Backbone Port Cost
$2(\alpha+1)P_{term}C_{OXC} + P_{term}C_R$

Total Backbone Port Cost
$(1+2\beta\alpha)P_{term}C_R$

Router only cost is less when
$CR = C_R/C_{OXC} < (\alpha+1)/\beta\alpha$

- C_R = router port cost per λ
- C_{OXC} = OXC port cost per λ
- β = factor representing statistical multiplexing
- $\alpha = P_{thru}/P_{term}$

Results:



BFR = Big Fat Router

OXC=Optical Cross Connect

IP / WDM Traffic Engineering

- Traffic Engineering Objectives
- The goal of traffic engineering is to optimize the utilization of network resources
  - reducing congestion & improving network throughput
  - more cost-effective
  - efficiency gained through load balancing
  - requires macroscopic, network wide view
- IP Layer TE Mechanisms
  - MPLS Explicit Routing
- WDM Layer TE Mechanisms
  - WDM Lightpath Reconfiguration
    - IP Network Topology Reconfiguration

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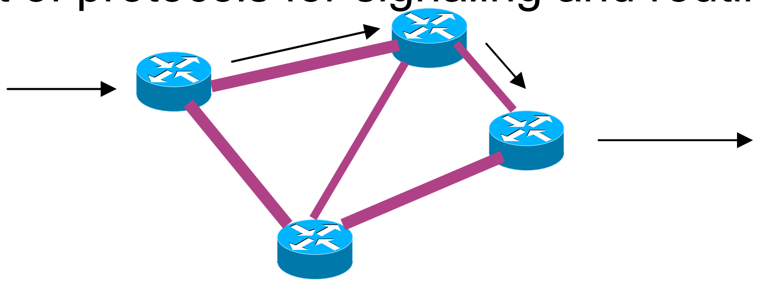
IP layer traffic engineering

- In conventional IP routing, each router makes an independent hop-by-hop forwarding decision
  - routes packets based on longest destination prefix match
  - maps to next hop
- In MPLS, assignment of a packet to a FEC is done just once as it enters the network, and encoded as a *label,* each label is associated with a path through the network
  - label sent along with the packet for subsequent routers to find the next hop
- MPLS: *explicit control of packet paths:*
  - simpler forwarding
  - easy support of explicit routing: label path represents the route
- MPLS uses a set of protocols for signaling and routing



BUT, IP layer traffic engineering is constrained by the underlying network topology

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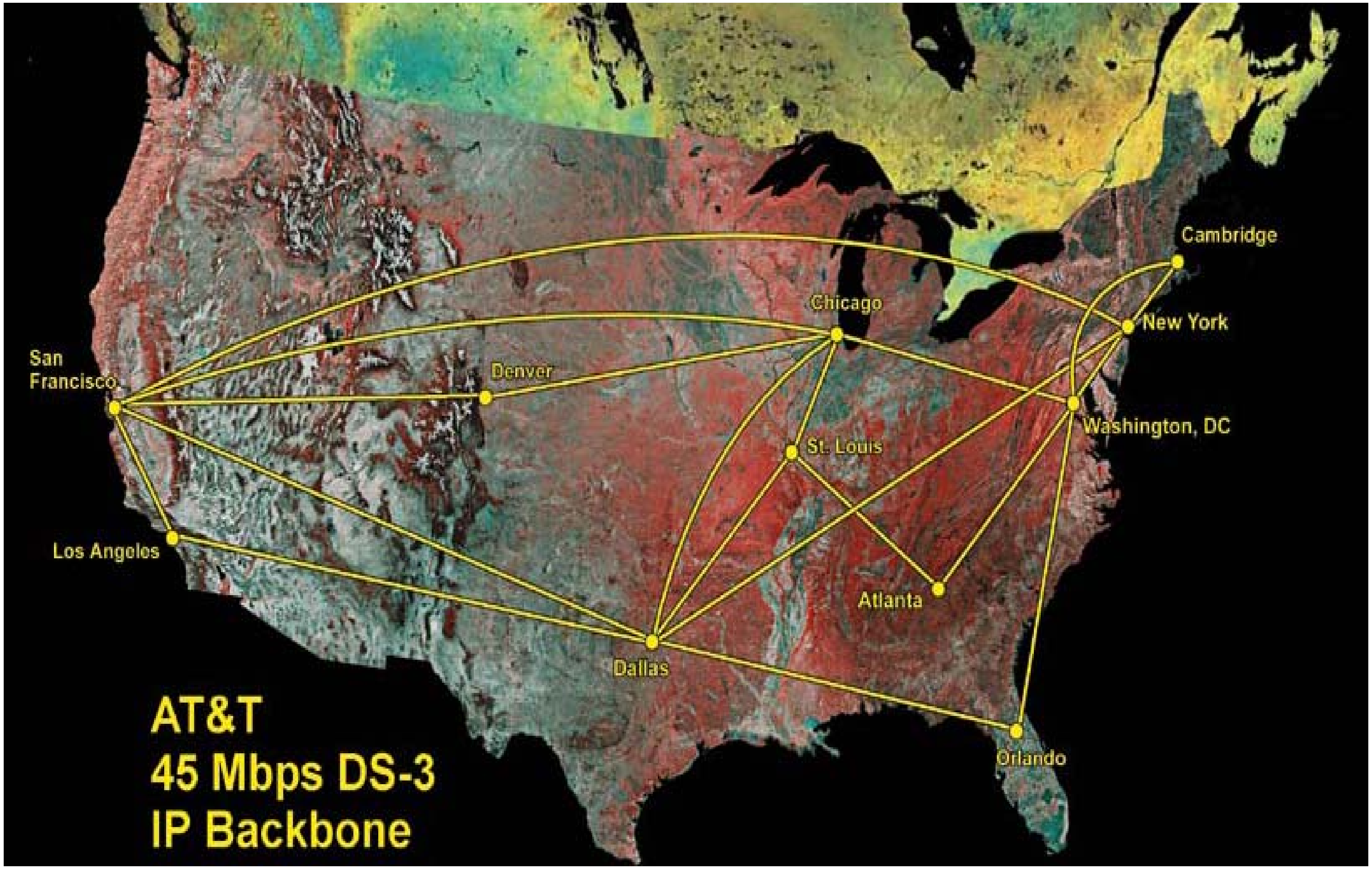
Traffic Engineering Using Network Topology Reconfiguration



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Simulation Studies -- AT&T IP Backbone

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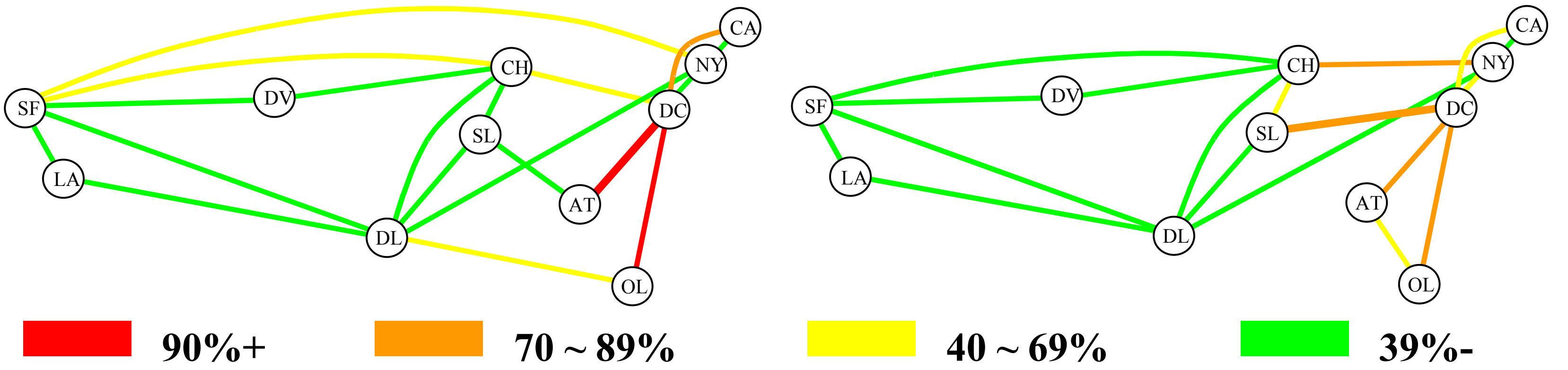
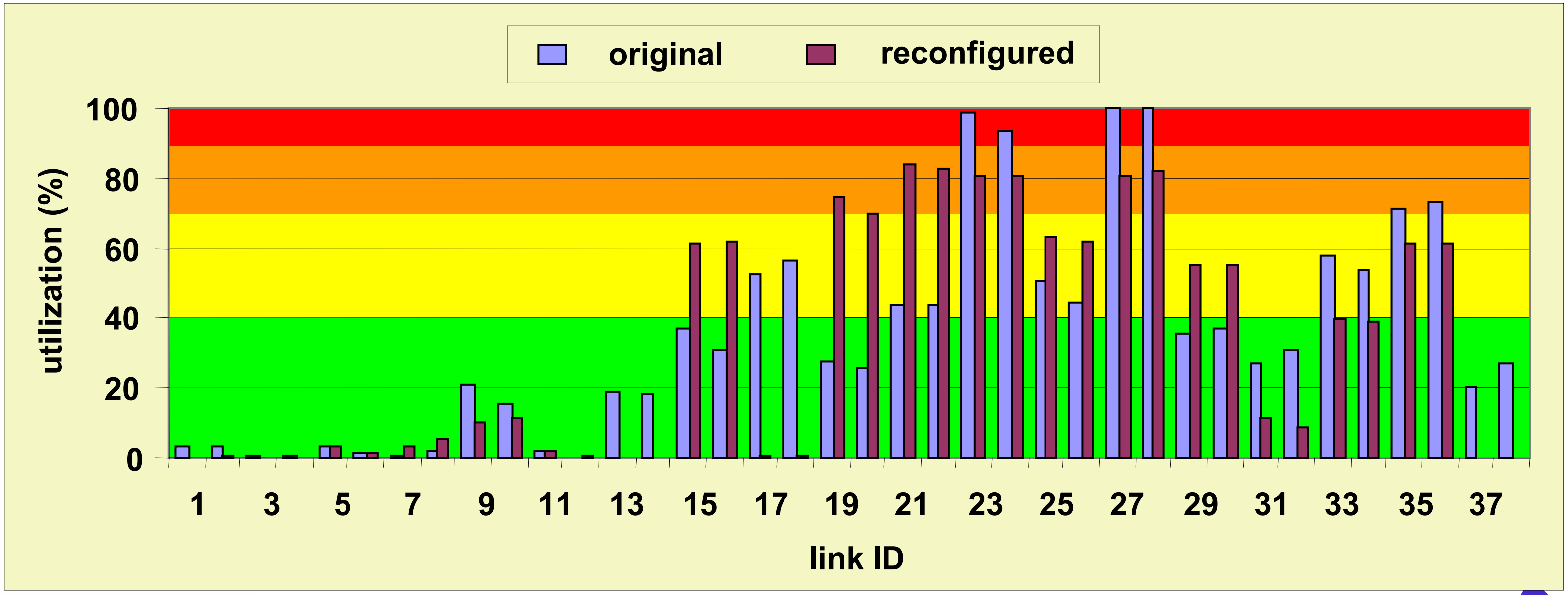
Effect of reconfiguration on link load distribution





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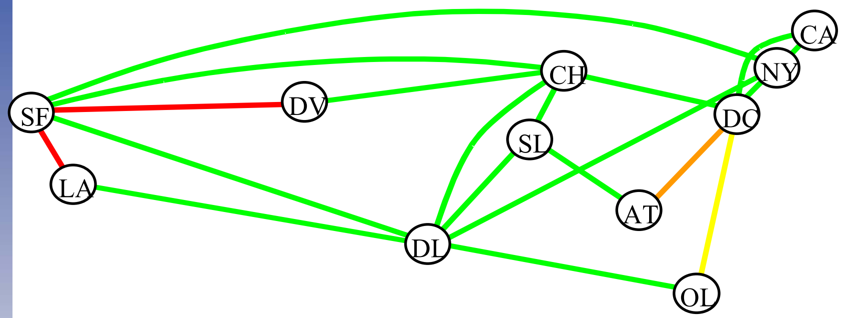
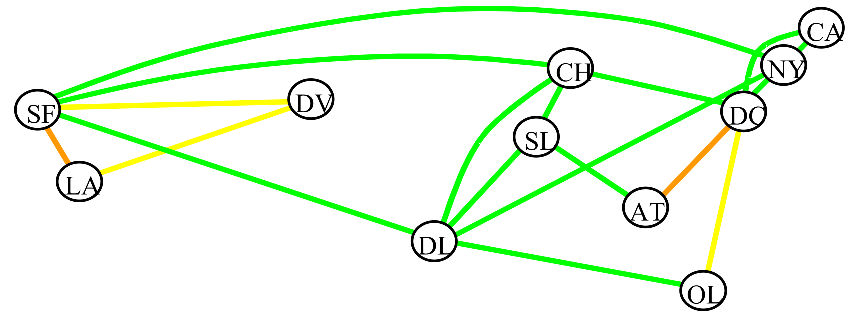
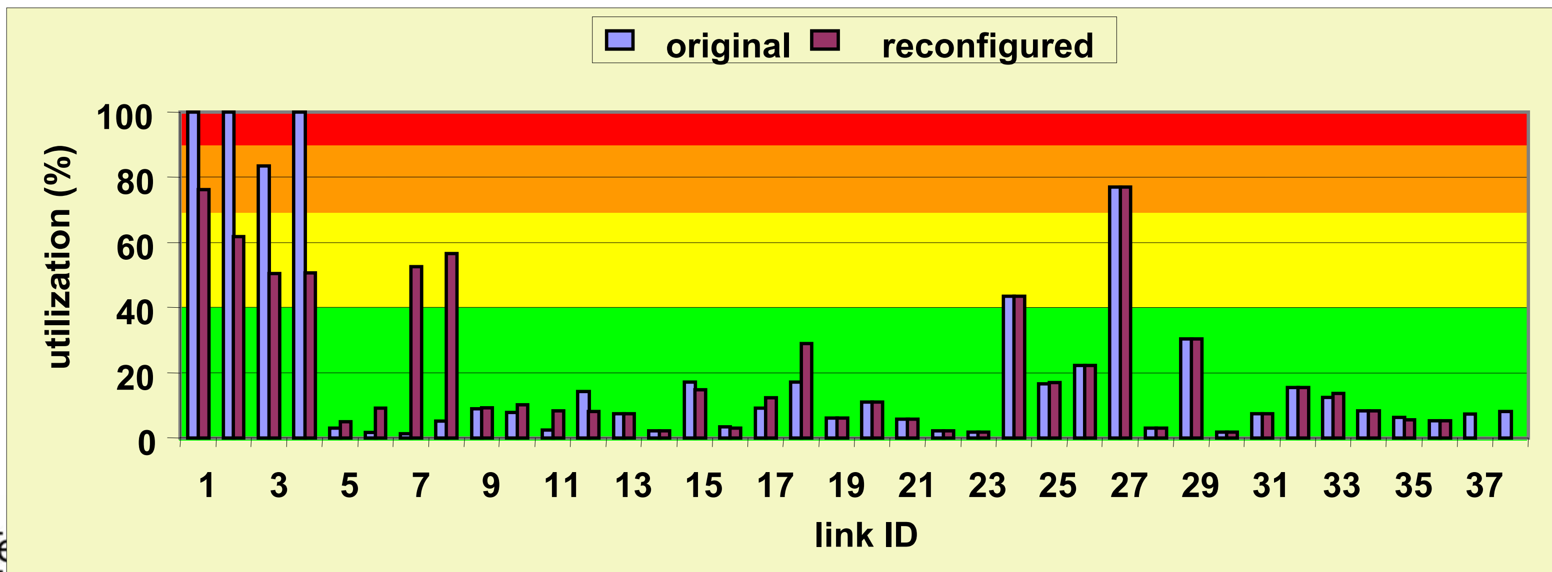
PM Traffic Demands and Link Load Distribution





90%+ | 70 ~ 89% | 40 ~ 69% | 39%-



Network Reconfiguration for Traffic Engineering

Tremendous value……..

- Congestion relief, load balancing
- Cost savings in router ports
  - 44% in this simulation
- WDM layer reconfiguration works in concert with IP layer TE (i.e., MPLS)

IP and the optical layer:

Recap:

Reconfigurable optical layer offers:

- ultra-high capacity transport
- lower cost node architecture
- enhanced traffic engineering capability

- *Next:*
  - IP/WDM network management paradigms
  - IP and optical layers are independent
    - The optical overlay model
  - IP and optical layers are integrated
    - for rapid provisioning and most efficient use of network resources?

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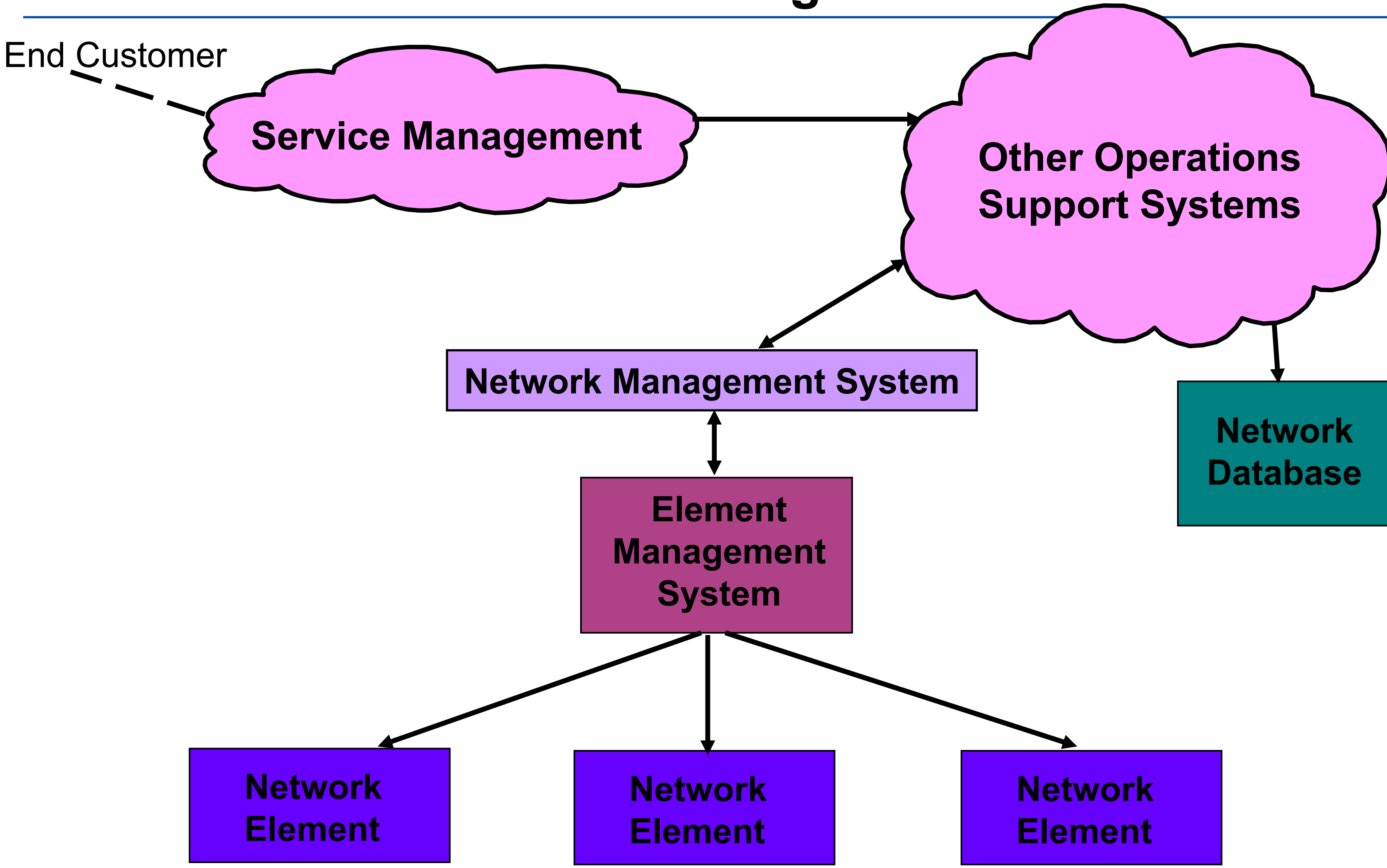
Network Management



NE's = Optical, IP, SONET, etc

Dynamic Networking

- In a static world:

  Infrequent need to traffic engineering

  put connections up and leave them 'for 20 years'

  centralized net management works beautifully

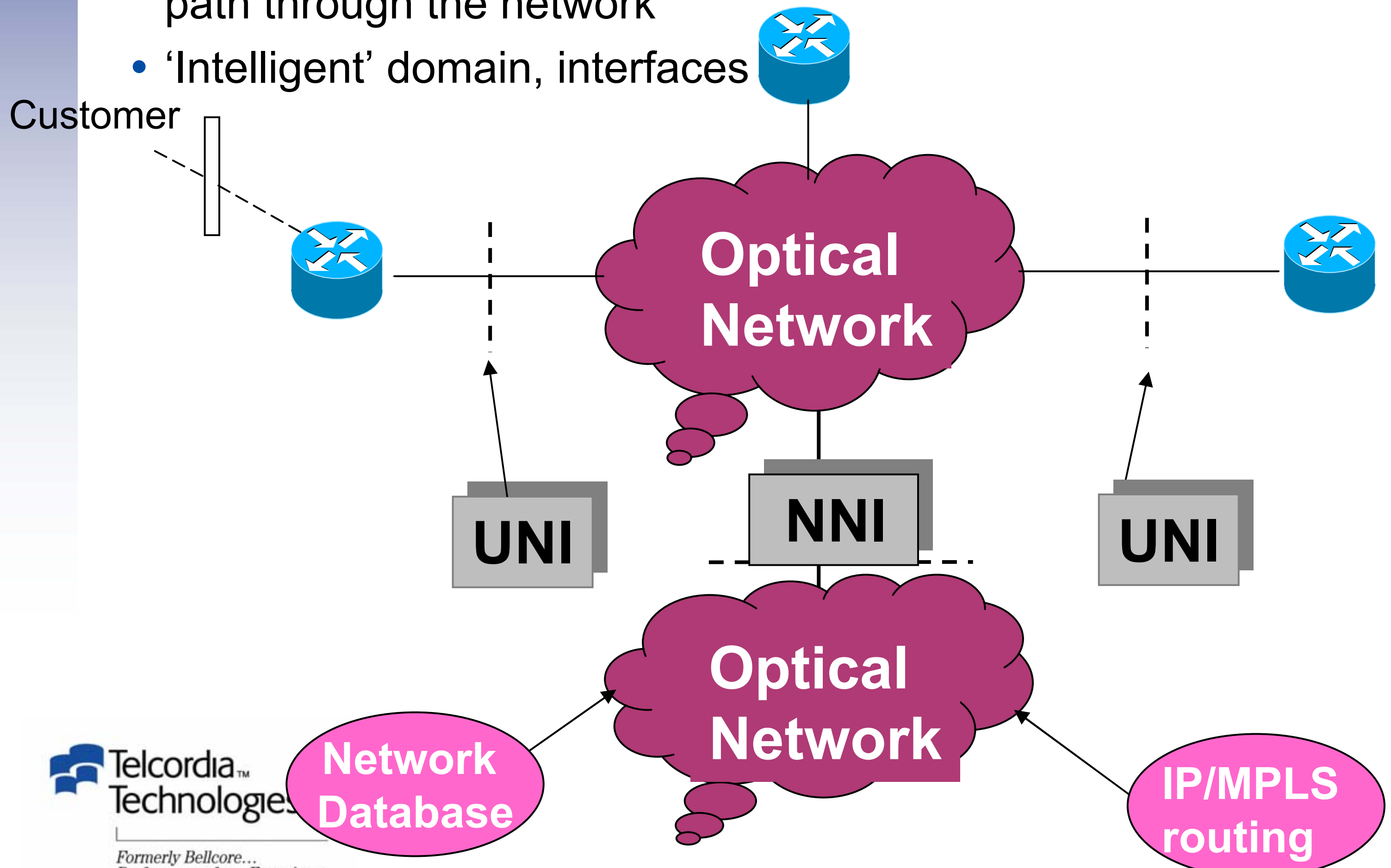
- Coming soon?
  - Need to accommodate service requests on a more dynamic basis
  - Centralized network management may not be able to respond rapidly enough, and is not scalable

- Service drivers for dynamic networking
  - Variable bandwidth on demand
  - Storage Area Networks (SAN)
  - Disaster recovery networks
  - High-speed Internet connectivity to ISPs and ASPs.

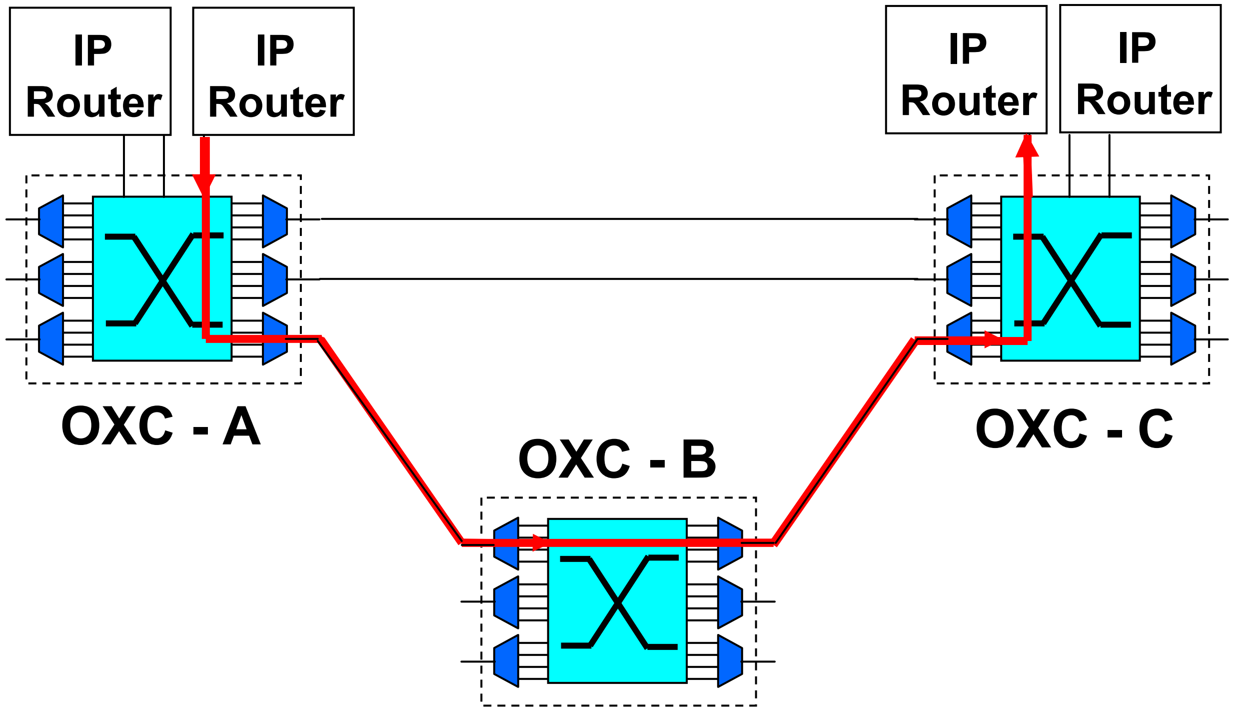
New paradigm:

- Bandwidth requests from IP layer are serviced directly by the optical layer
- Routing within the optical network uses **IP-MPLS** protocols:

  Autodiscovery of neighbors(routing table), path selection according to service parameters(bit rate, level of protection, etc), signaling to establish path through the network
- 'Intelligent' domain, interfaces

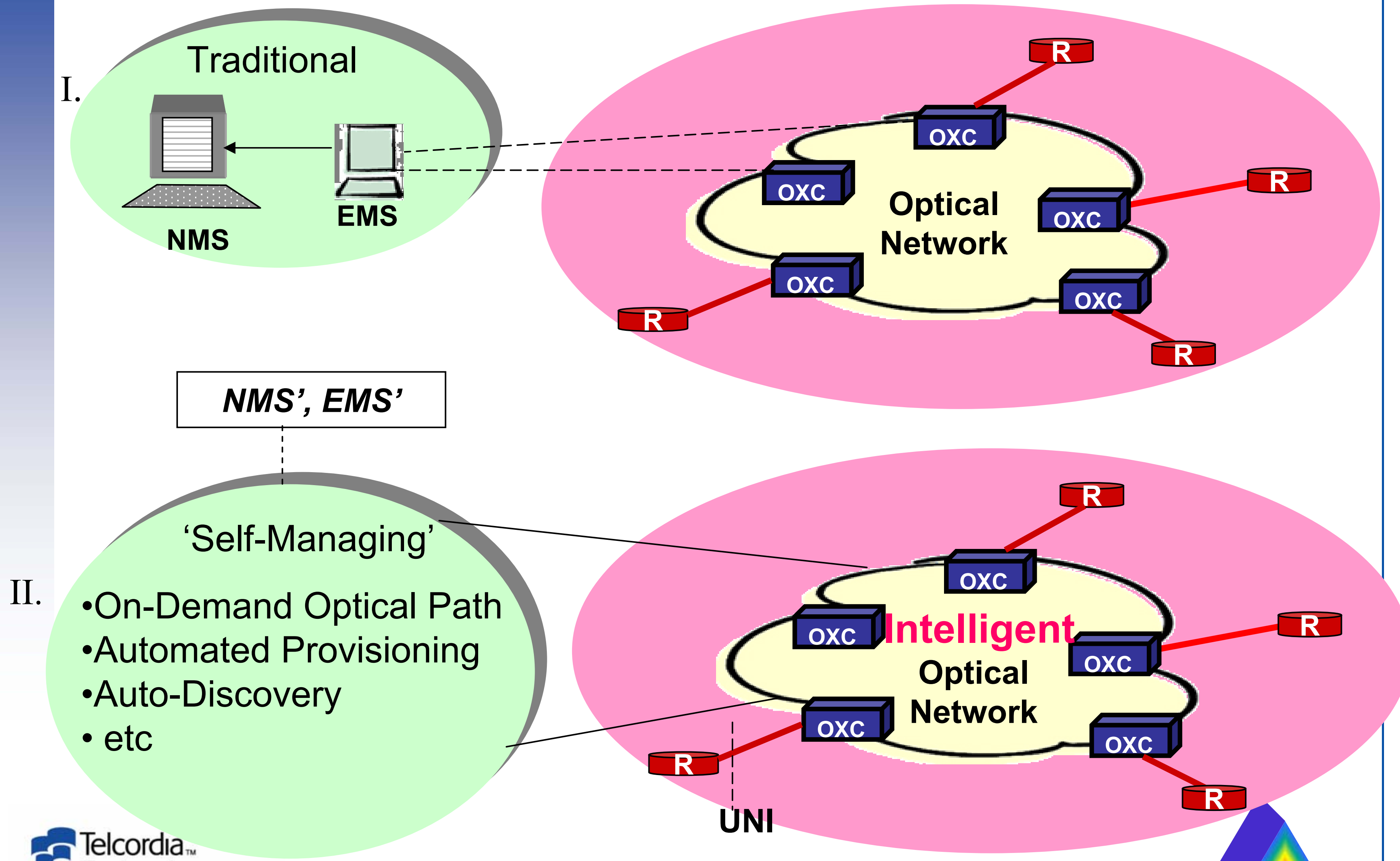


Example: Dynamic Set-Up of Optical Connection



1. Router requests a new optical connection
2. OXC A makes admission and routing decisions
3. Path set-up message propagates through network
4. Connection is established and routers are notified

Distributed management and 'intelligent' optical networks



Required Functionality in UNI 1.0

- Rapid provisioning of circuits between clients
- Various levels of circuit protection and restoration
- Signaling for connection establishment
- Automatic topology discovery
- Automatic service discovery

- Optical Internetworking Forum is pursuing UNI and NNI definition

    UNI 1.0 defined; UNI 2.0 under development

    NNI under development (ETA 12/02)

- All major vendors have implemented 'control plane';

    carrier deployment just beginning

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Recap: (client/server paradigm)

- **Client network routing protocol and optical network routing protocol are run *independently* (they may use the same protocols).**

- **There is *no exchange of routing information* between client and optical layers.**

- **So coordination eg for traffic engineering, or for restoration, is still moderated by a centralized management system.**

Further integration of IP and optical planes: Peer model

- **Peer Model**
  - **A *single* routing protocol instance runs over both the IP and Optical domains**
  - **A common protocol is used to distribute topology information**
  - **The IP and optical domains use a common addressing scheme.**

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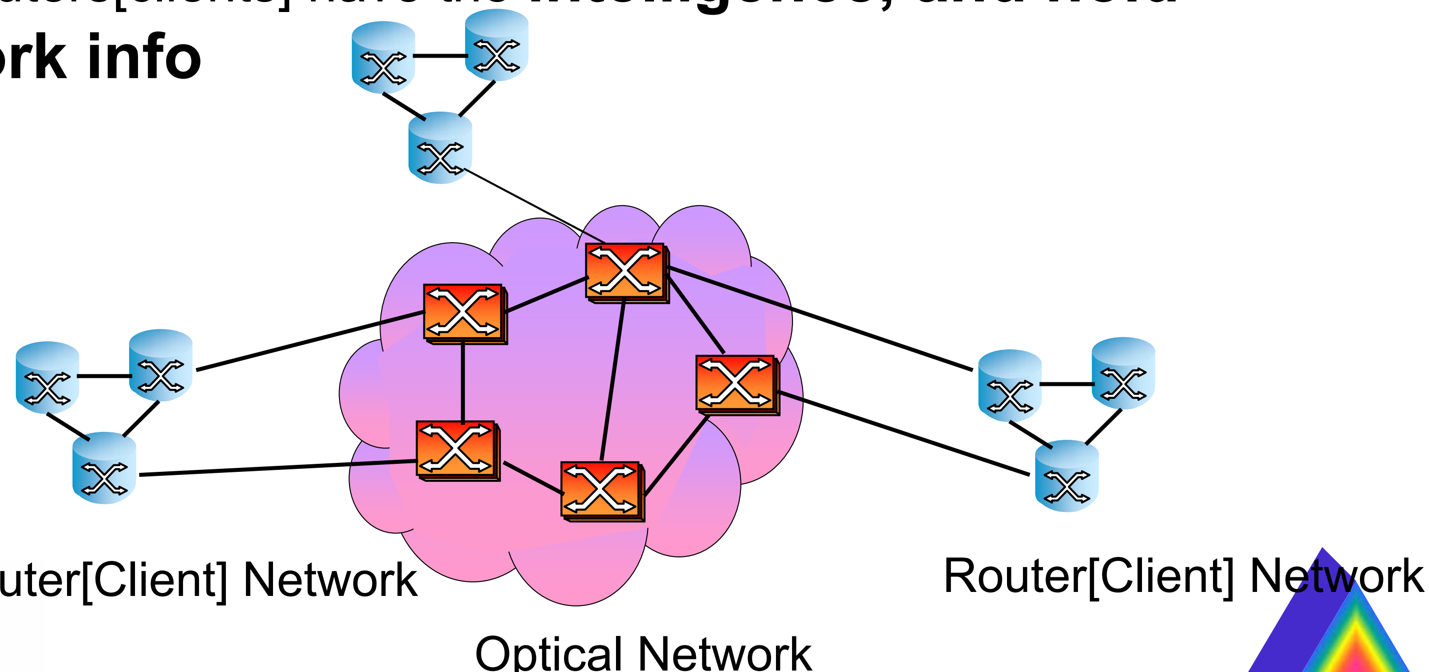
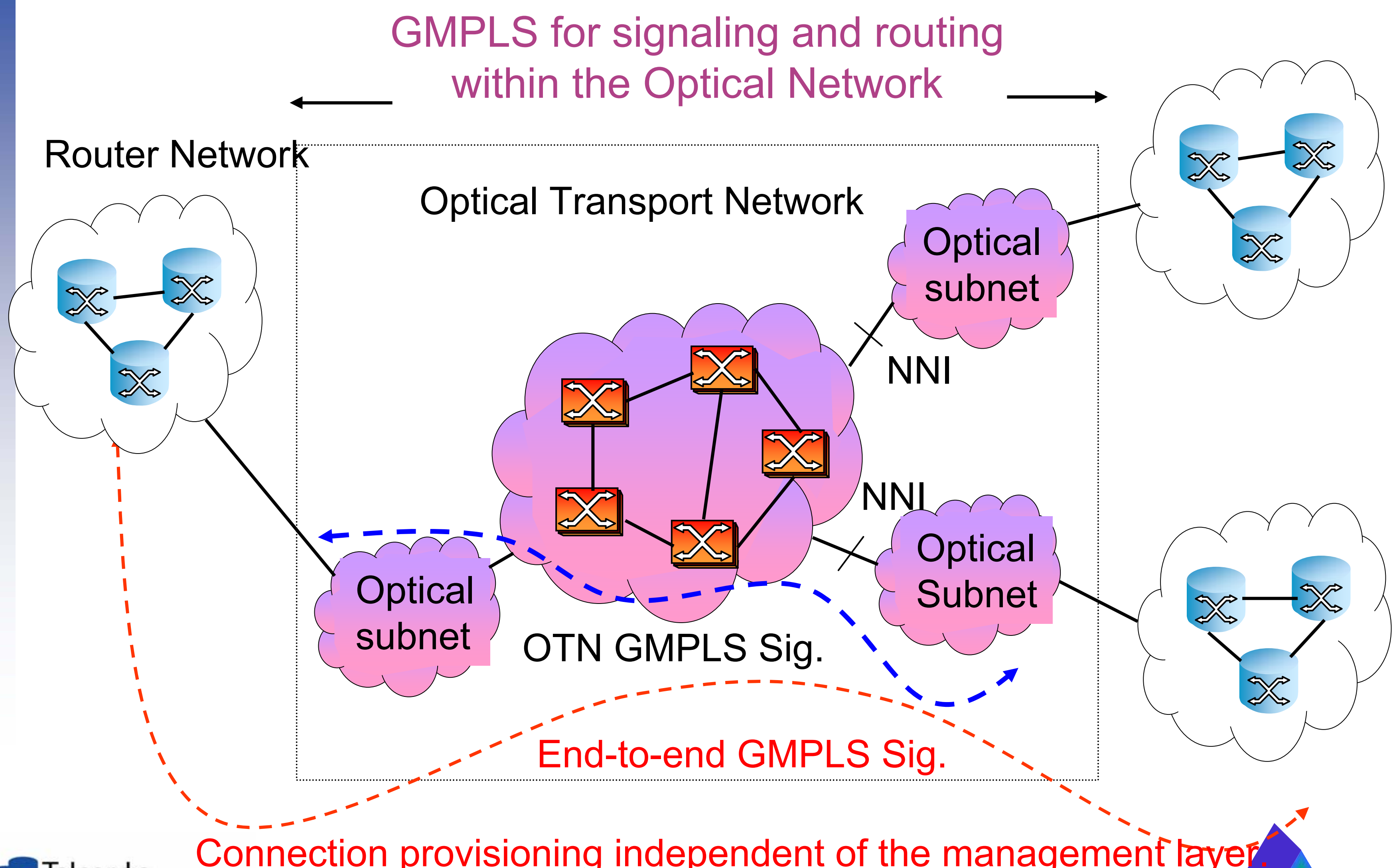
Peer Model

- No ‘UNI’: The entire client-optical network is treated as single network. The same protocols (G-MPLS) are used in **both** optical and client equipment.
- Client devices (e.g. routers) have complete visibility into the optical network, and are responsible for computing paths and initiating connections
- I.e., Routers[clients] have the **intelligence, and hold network info**



The ultimate vision: integrated IP/optical management



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Summary

- Optical networking is core to the development of IP networks and services
  - Both transport and switching
- How far things will go towards ‘the ultimate vision’ is an open question
  - **More than IP traffic in networks (GbE, SONET)**
  - **Dynamic service provisioning: when?**
  - **Policy, security and interoperability issues**
- Large carriers have a lot of inertia
- Transitions to new paradigms cost money