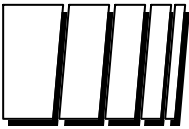




GMPLS Actively Managed WDM Testbed

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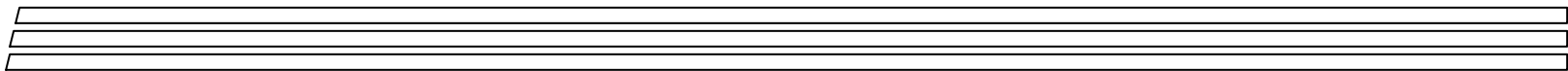
Objective

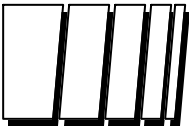
● **Actively managed GMPLS Network**

- Actively managed reconfigurable WDM optical network
 - » Ultra-high capacity (~10Tps)
 - » Scalability and efficiency of bandwidth utilization
 - » Reconfiguration is built into the traffic engineering process
- Delivery of quality of service (QoS)
 - » Capable of providing variable levels of QoS according to service level agreements (SLAs)
- Considerable resiliency
 - » Prompt detection of failures
 - » Fast protection switching/restoration
- Advanced network control and management

● **Base on optical Ethernet**

- Internet traffic is dominated by Ethernet packets
- Introduces QoS traffic engineering and Differentiated service
- Low cost line rate and Ethernet switch devices
- Very efficient packet delivery





Current GMPLS and Optical Ethernet Approaches

- **Inefficiency of current GMPLS implementation**

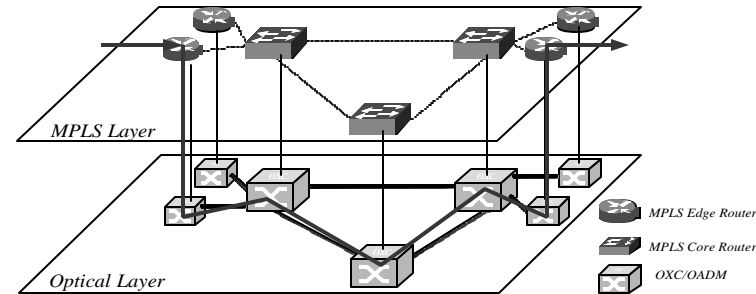
- All-optical routing in the core region of the network
 - » Coarse traffic granularity
 - » High traffic blocking rate
 - » Limited reconfiguration capability
 - » No grooming; bandwidth utilization efficiency is limited
- MPLS and optical layers are managed separately
 - » Complicates the OAM&P
- Layer 2 is passive and non-reconfigurable

- **Difficulties of current Optical Ethernet**

- No carrier-class QoS
- Lack of efficient OAM&P methods
- Inefficient protection/restoration schemes

- **Existing improvement attempts on Optical Ethernet**

- Resilient Packet Ring (RPR)
 - » Specially designed MAC for packet transport over fiber-optic rings
 - » Introduces SONET-like protection and restoration schemes to optical Ethernet
 - » Not suitable for other regular topologies, e.g., mesh topology
- Layer-3 switching
 - » Merges layer 2 switching and layer 3 routing functions to a single switch box
 - » Utilizes reconfigurable features of layer 2 to some extent



Combination of GMPLS and optical Ethernet

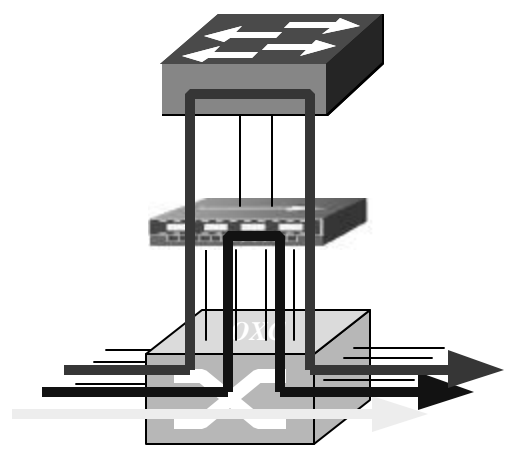
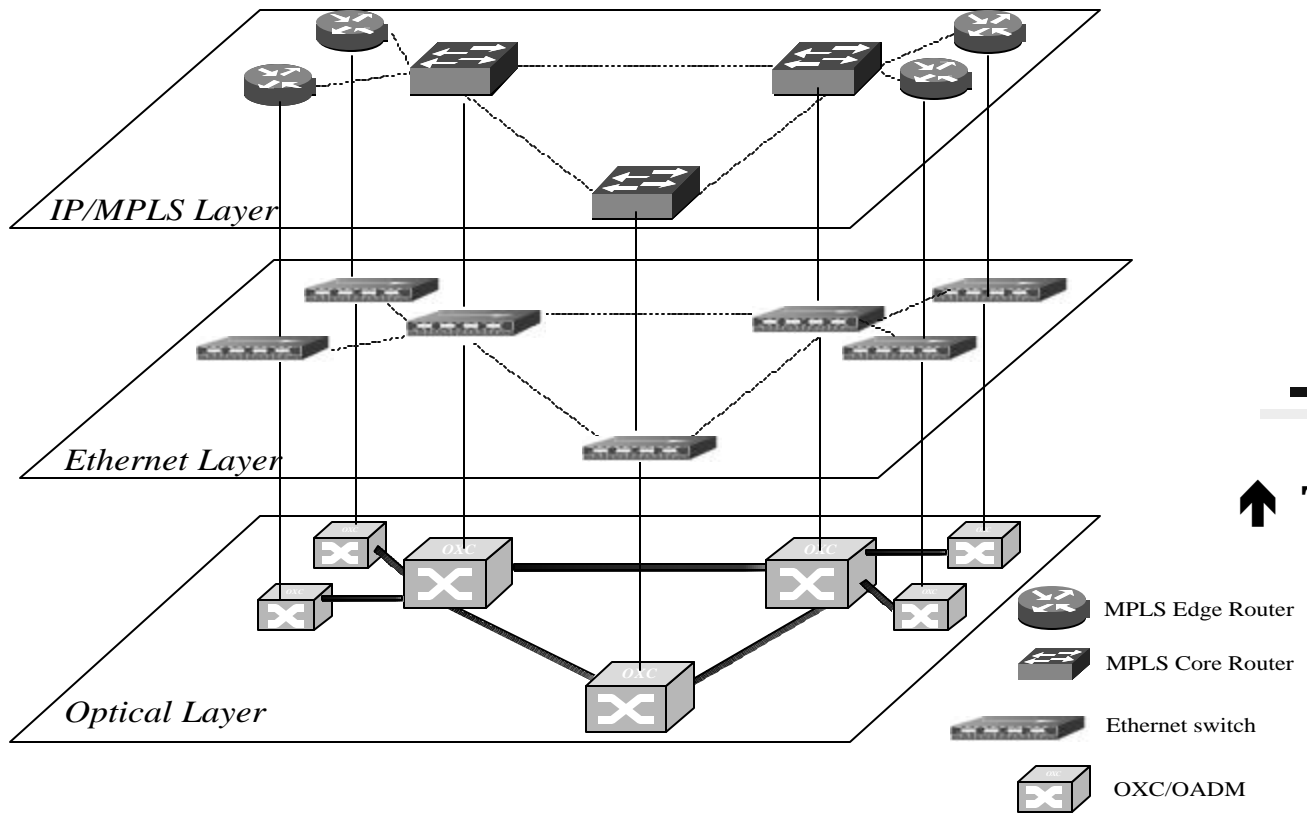
-Incorporates both QoS and resilience features of GMPLS and efficiency of Ethernet



Our GMPLS Testbed

- ✓ Implements an *Integrated Reconfigurable Ethernet (layer 2) + Optical **Switching Layer***
 - Even with legacy Ethernet switches (routing and signaling protocols required)
 - Integrated management of the optical layer and Ethernet layer through QoS traffic engineering
- ✓ Enables *traffic grooming* and *O/E/O wavelength conversion* at the core of the network
- ✓ Wavelength information and MAC addresses are utilized collectively to perform the GMPLS “label” functions

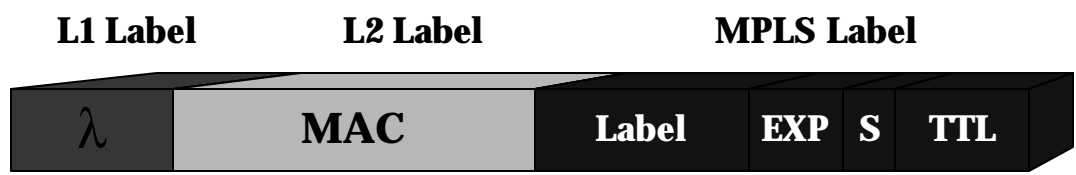
System Architecture



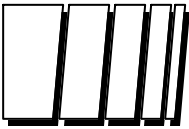
↑ Three forwarding schemes

- all-optical
- O/E/O at Ethernet layer
- O/E/O at IP/MPLS layer

– Different forwarding scheme can have different QoS level, e.g., bandwidth, latency, jitter, etc.

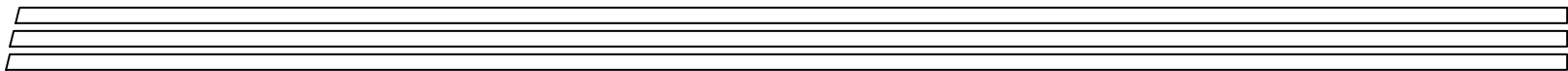


➔ The label structure



Benefits

- **QoS path provisioning**
 - The device performance/response parameters are calibrated for each QoS level
 - QoS paths are set up according to the committed service level agreement (SLA)
 - Paths can be adjusted, i.e., reconfigured, according to traffic engineering decision
- **QoS path performance improvement**
 - Path latency reduction
- **Efficient bandwidth utilization through O/E/O wavelength conversion and traffic grooming**
- **Potential system cost reduction**
 - Inexpensive Ethernet switch devices
 - Low cost Ethernet deployment
 - Fast service provisioning

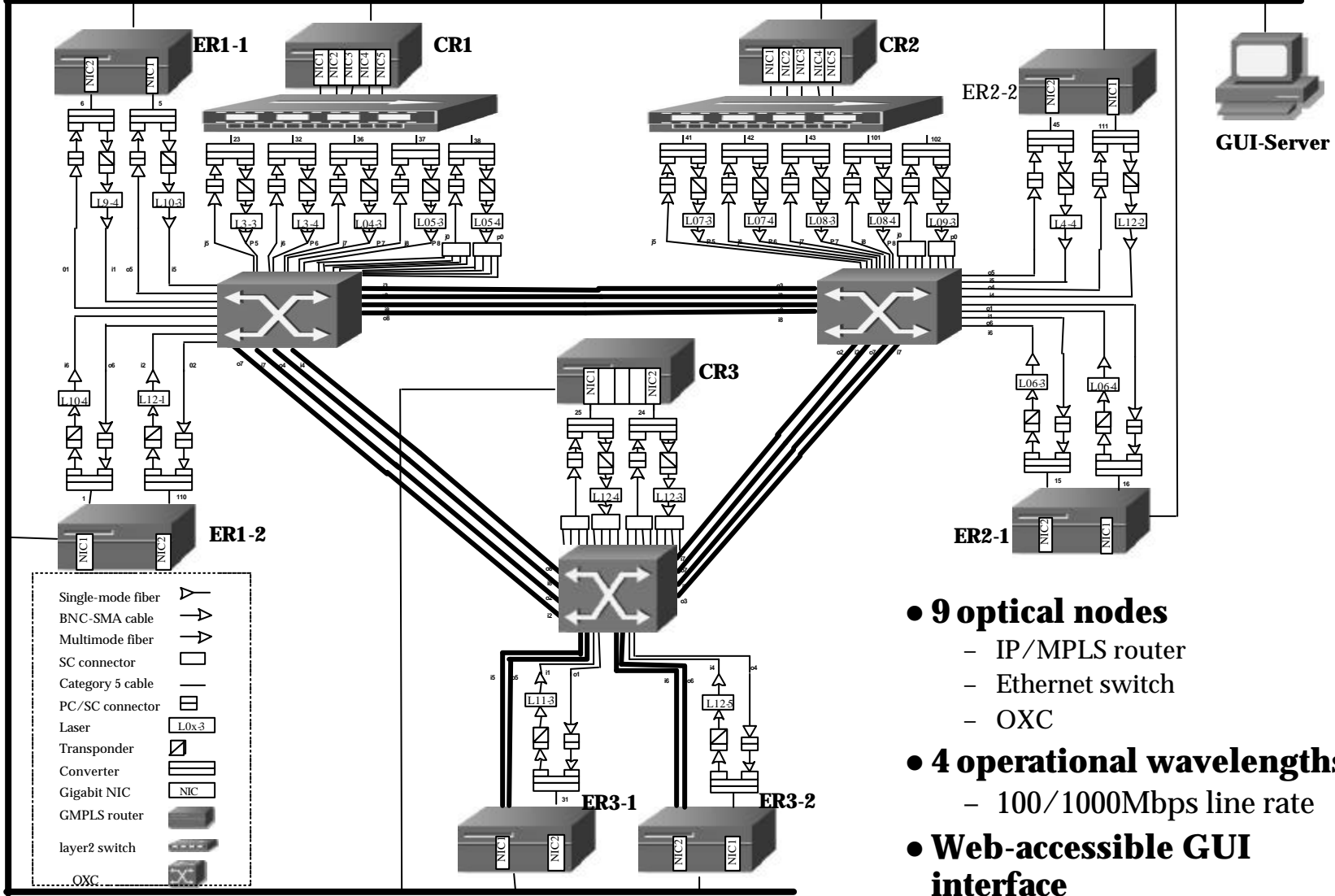




*Hardware subjects
for UMBC MPI S Testbed*

The UMBC GMPLS Optical Testbed

Signaling channel



- **9 optical nodes**
 - IP/MPLS router
 - Ethernet switch
 - OXC
- **4 operational wavelengths**
 - 100/1000Mbps line rate
- **Web-accessible GUI interface**



Traffic Generator and Testing Software

- Software: based on the 3rd party software as follows
 - Netperf
 - » Used to generate background traffic
 - » Used to randomly generate traffic
 - » Used to generate multiple user sessions
 - Iperf 1.1.1
 - » Used to test the packet drop rate (PDR), Packet Jitter, User throughput
 - ICMP Ping
 - » Use to get the path round-trip latency



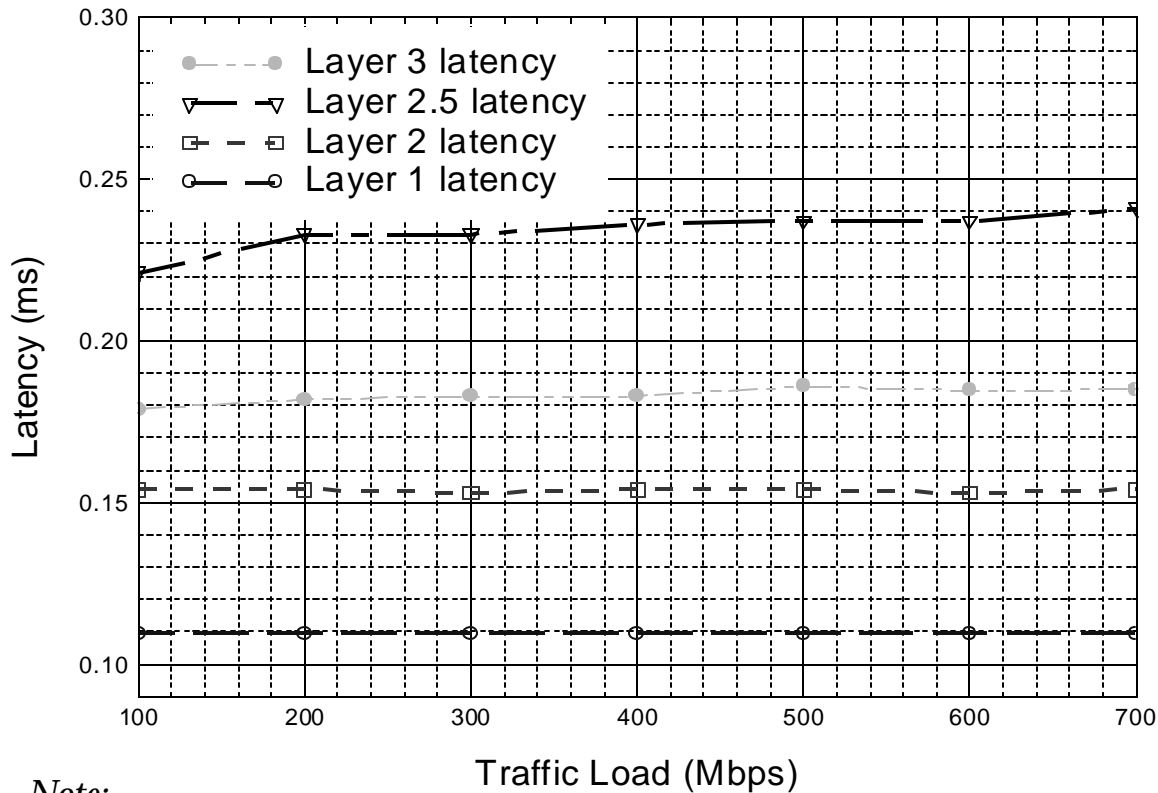
PC throughput capability

	DATA TYPE	Maximum TCP (loopback) /UDP throughput	CPU utility rate-system
Client Dell SC600	TCP STREAM	3.51G(iperf) 4.1G(netperf)	95%(iperf) 95%(netperf)
CR	TCP STREAM	2.290G(netperf) 2.2G(iperf)	98%(netperf) 92~96%(iperf)
ER3-1,ER3-2 ER2-2,ER2-1	TCP STREAM	2.231G(netperf) 2.2G(iperf)	96%(netperf) 91~94%(iperf)
Client Dell SC600	UDP STREAM	3.52G(iperf)	93%(iperf)
CR	UDP STREAM	2.33G	83%
ER3-1,ER3-2 ER2-2,ER2-1	UDP STREAM	2.53M	70%

- Experiment setup: local loopback



Path Latency Reduction

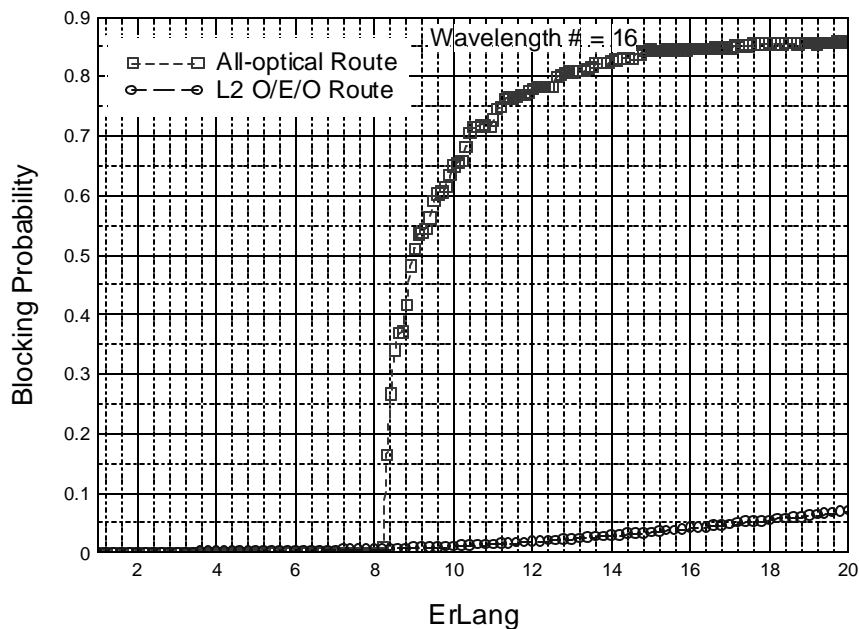


Note:

- Test results are extracted from the 9-node UMBC Optical testbed.
- Results only show single node latency.
- Equipments used in the measurement : Cisco Catalyst 3550 router, Intel 100Mbps Ethernet switch, PC-based NIST MPLS switch (Pentium 4 @ 2.0Ghz).
- In this test, Layer 2.5 latency is limited by our home-built MPLS switch. Layer 2.5 latency should be smaller if commercial MPLS switches are used.
- Real values of throughput and latency may vary, if different router/switch/OXC devices were used. However similar performance behavior is expected.



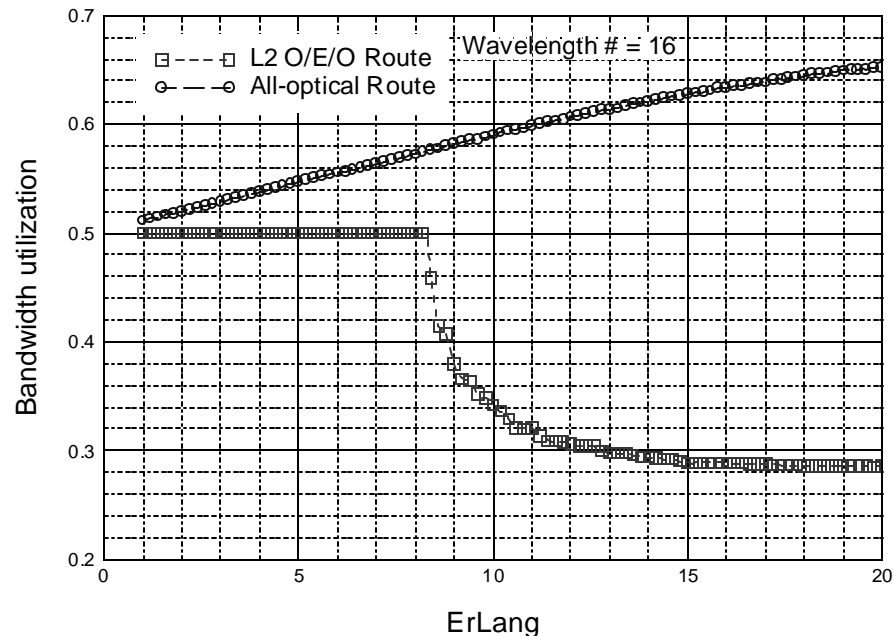
Analysis on Bandwidth Utilization Efficiency



↑ Comparison of system blocking probability

Note:

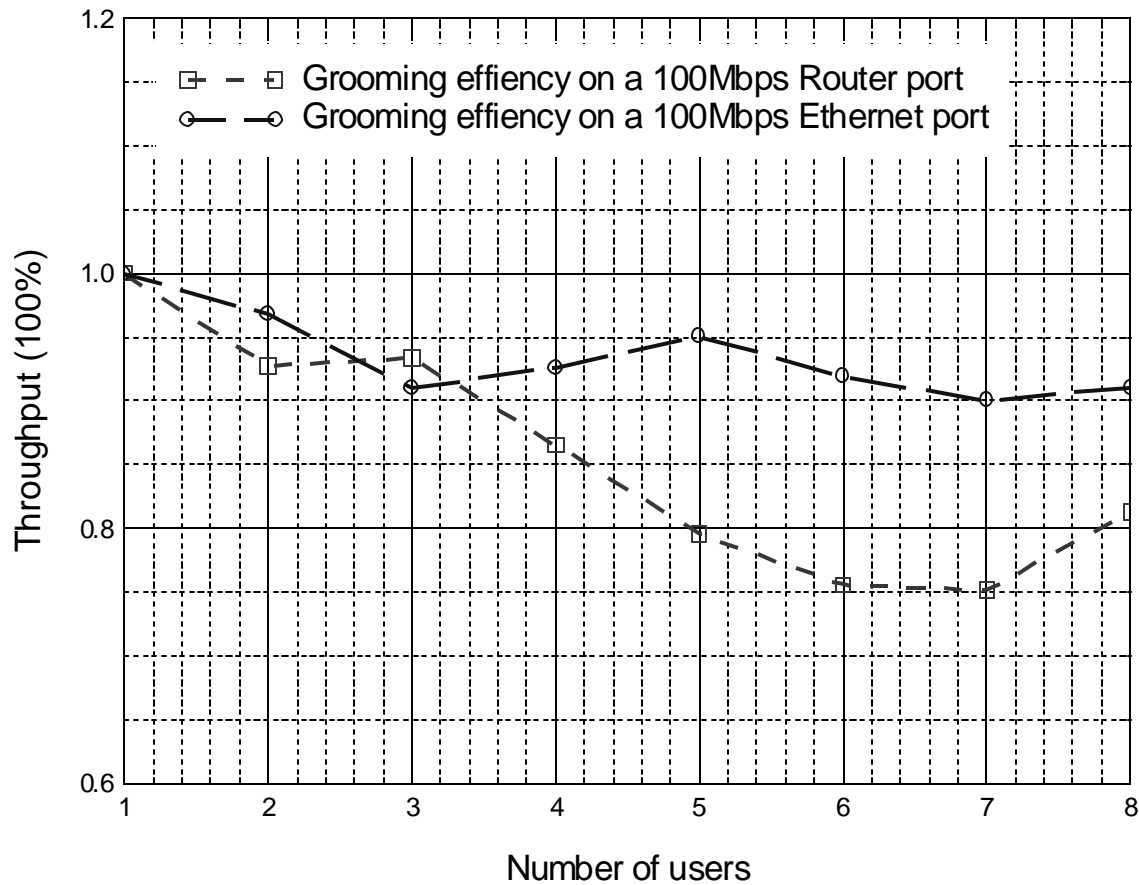
- The comparison is based on the 30-nodes NSFNET topology assuming that each node has full L2 O/E/O capability
- Each individual bandwidth request ≤ 2 Mbps
- All traffics are Internet best-effort traffic
- All-optical : adaptive routing and first-fit (FF) wavelength assignment
- O/E/O: standard SPF calculation



↑ Comparison of bandwidth utilization on a single node



Efficiency of Traffic Grooming

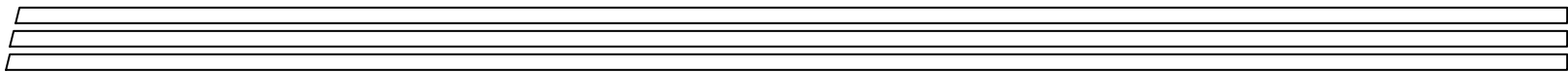


Note:

- Test results are acquired from the UMBC Optical testbed
- Equipments used in the measurement : Cisco Catalyst 3550 router, Intel 100Mbps Ethernet switch
- Real values of throughput and latency may vary, if different router/switch/OXC devices were used. However similar performance behavior is expected.



GMPLS Operating System
Design Issues
for UMBC MPLS Testbed





The Operating System Is Based On...

- RFC GMPLS, MPLS Drafts
- FreeBSD Rel. 3.3
- NIST MPLS Switch engine
- Alternative Queuing (ALTQ)
- ReSerVation Protocol (RSVP) + TE extension
- OSPF-TE

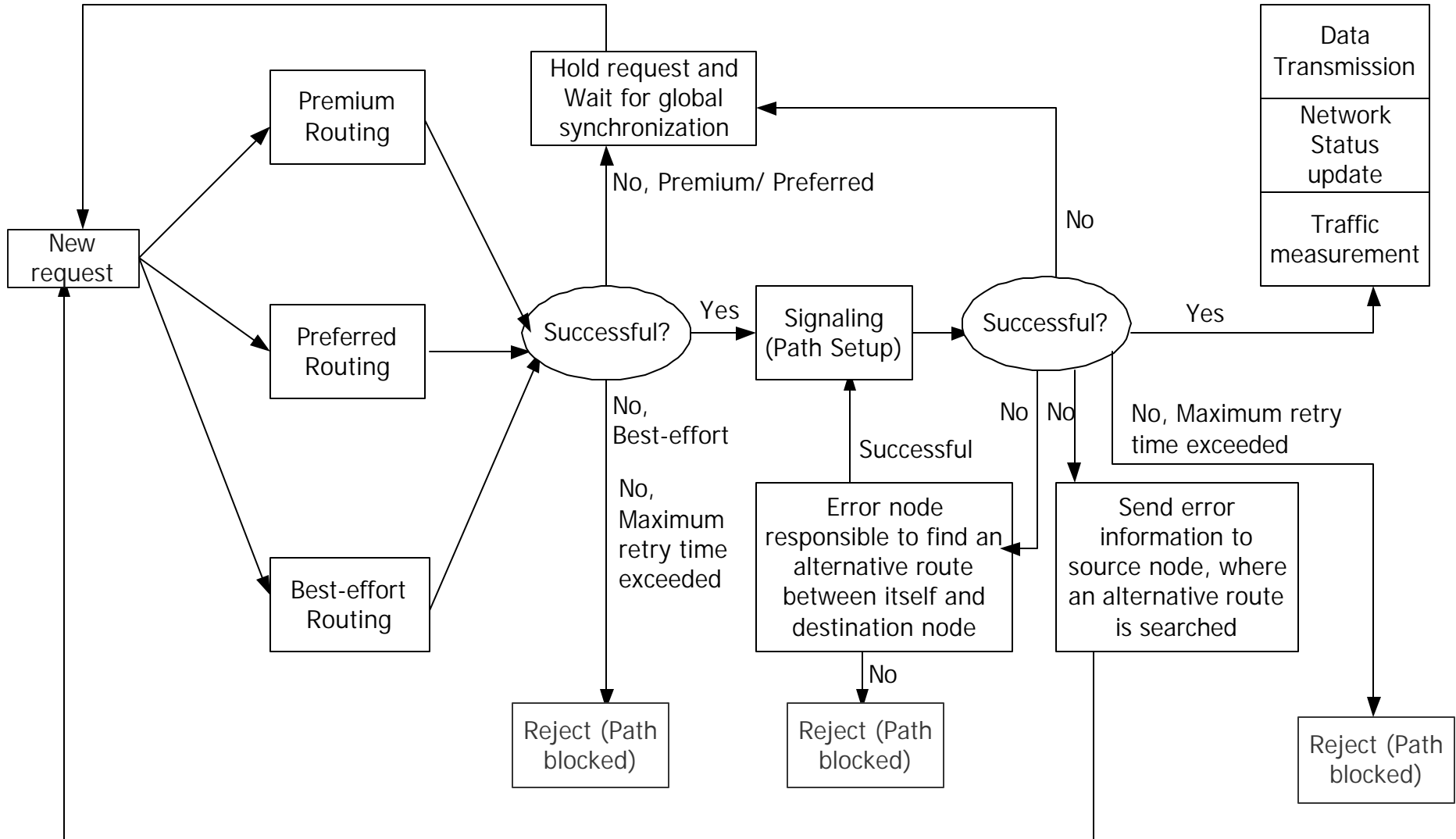


Our Special Considerations

- We assume full network-awareness at each node
 - A cluster network environment
- The QoS condition is treated as a binary constraint
 - Bandwidth, latency, packet drop rate
- No splitting traffic
- Traffic history is not considered
 - » Routing decisions are made independent of past traffic pattern
- Dynamic cost factor model
- Routing calculations based on heuristics



Routing & Signaling Process





Routing – Dynamic Problem

- Given
 - Current network status
 - A set of QoS requests arriving one at a time
- Objective
 - Maximize total number of successful connections
- Constraints
 - Bounded QoS for premium and preferred services
 - Wavelength continuity constraint at each fiber
 - Grooming constraint : total bandwidth of premium and preferred service at any Ethernet switch port cannot exceed the maximum physical outgoing bandwidth
 - » Assuming the Ethernet switch has DiffServ capability
 - Reconfiguration policy



Routing Design

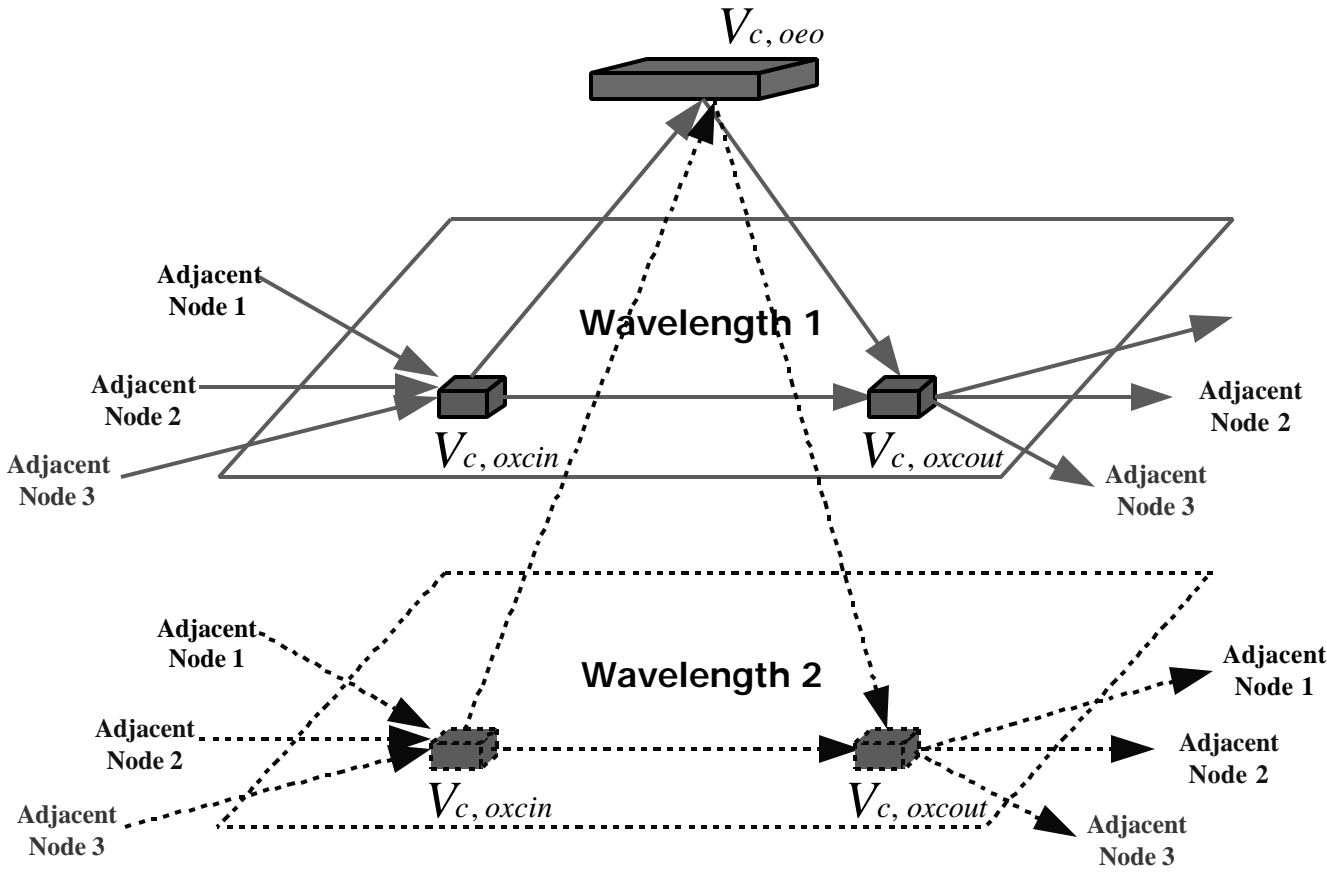
Delay-Constrained Least-Cost Routing (DCLC)

- Graph Extraction Problem
- S2 : Design of the Cost Function
- S3 : Design of the Delay Function
- S4 : Routing Heuristic



Graph Extraction

- Physical node extraction



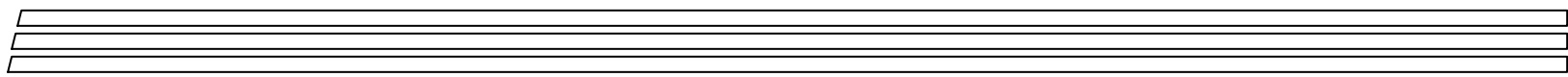
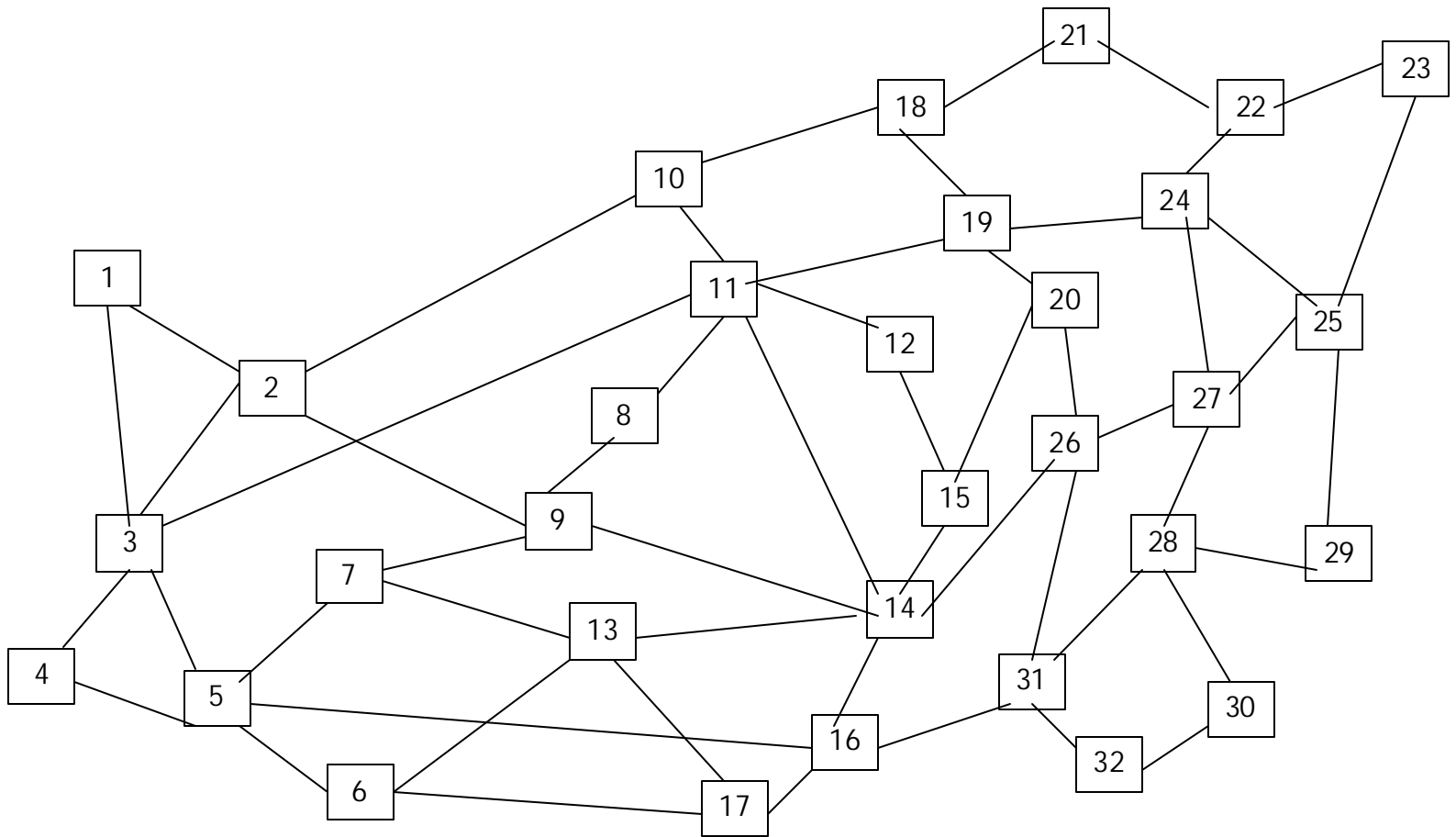
Routing – Sub-Problem 1

- S1 : Two-Pass Dijkstra for DCLC
 - First pass : calculate least delay LD_u from every node u to destination node d and establish the feasible subset of nodes $D(LD_{u'}) < D$
 - Second pass : calculate least cost path from source s to d ; at each relaxation, count only nodes u' that have $D(LD_{u'}) + \text{delay so far} \leq D$
 - Time complexity : $O(n \log(n) + m)$
 - The path found by DCLC is a feasible path



Two-Pass Dijkstra : Simulations

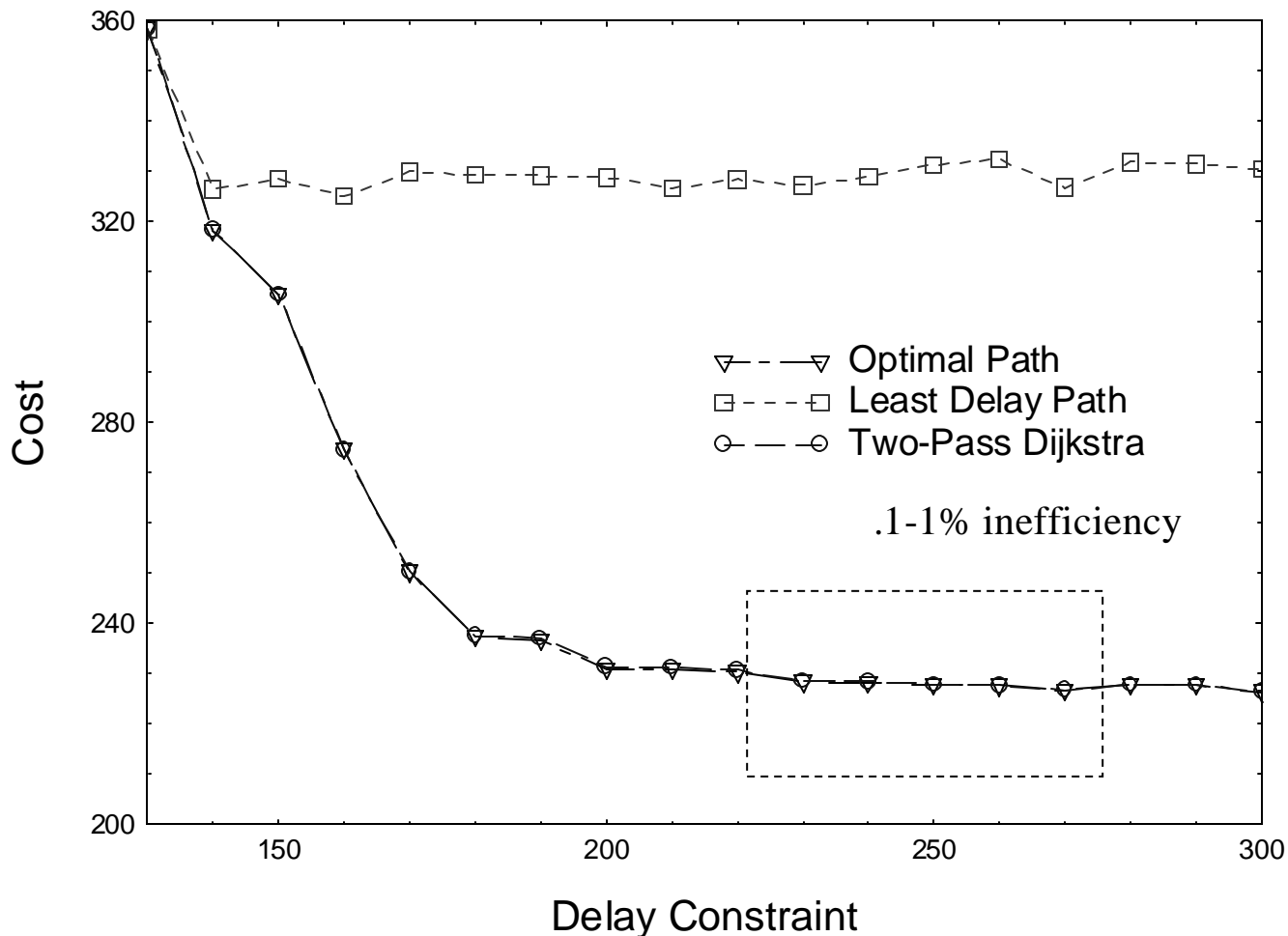
- NSFNET topology (32 nodes)
- Uniformly generated cost&delay on the graph





Two-Pass Dijkstra : Simulations

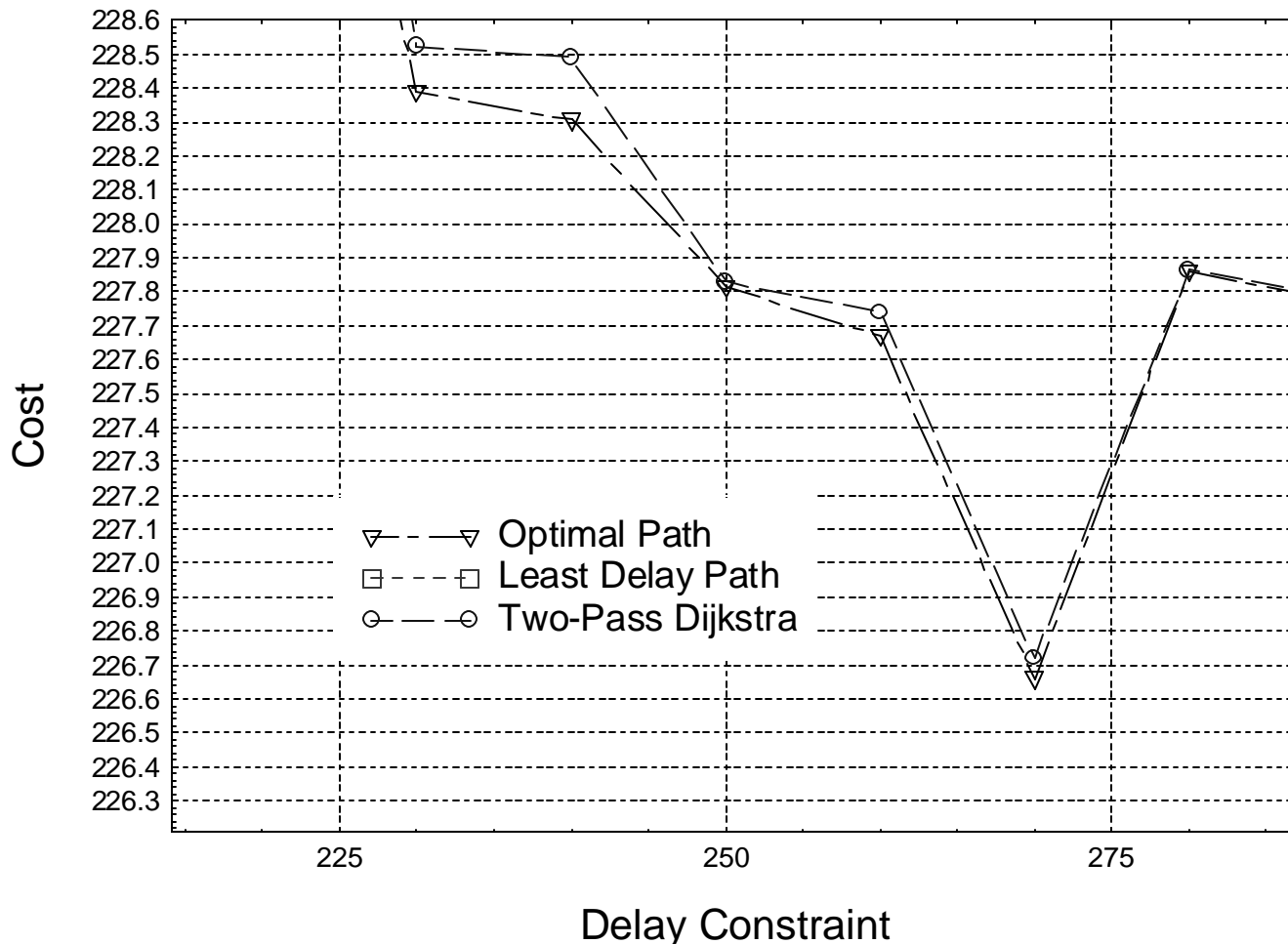
- NSFNET topology (32 nodes)
- Uniformly distributed cost&delay factors on the graph





Two-Pass Dijkstra : Simulations

- NSFNET topology (32 nodes)
- Uniformly generated cost&delay on the graph





Conclusions

- A novel hybrid network scheme that applies GMPLS on optical Ethernet is demonstrated
 - An integrated reconfigurable Ethernet (Layer 2) + Optical layer
 - QoS traffic engineering
 - » Efficient bandwidth utilization
 - » Cost-effective
- The testbed is utilized to develop network control and management schemes
 - Study advanced control plan issues
- Understand the issues related to actively managed network
 - When, where and how to trigger network reconfiguration
- In our system, each data packet connection can be *treated* as an independent circuit connection
 - The system can be used to study networks with much larger dimension