# *GMPLS Actively Managed WDM Testbed*

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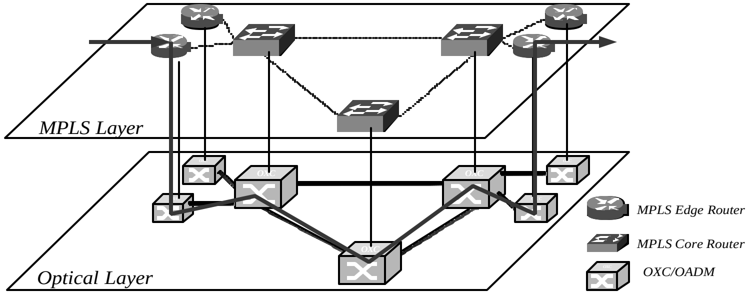
# *Objective*

- **Actively managed GMPLS Network**
  - Actively managed reconfigurable WDM optical network
    - » Ultra-high capacity (~10Tps)
    - » Scalability and efficiency of bandwidth utilization
    - » Reconfiguration is buit 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

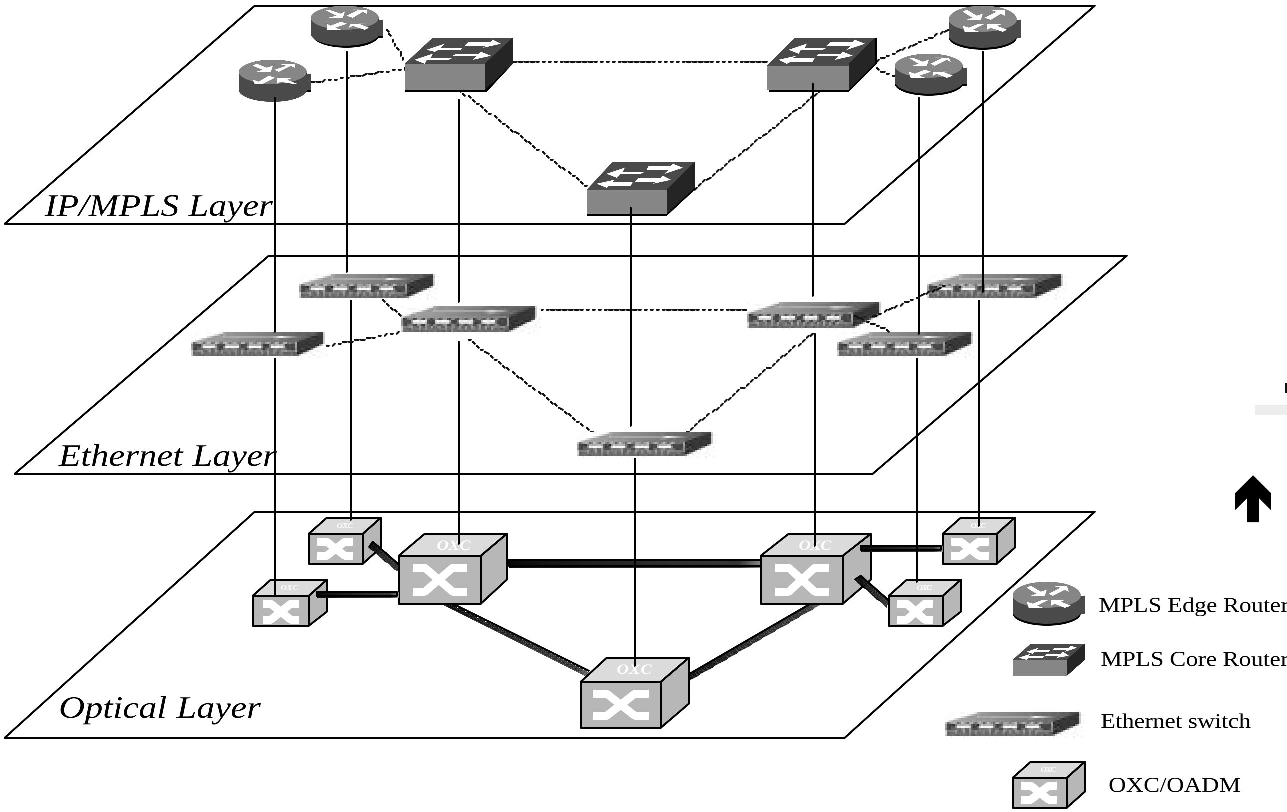
**Combination of GMPLS and optical Ethernet**

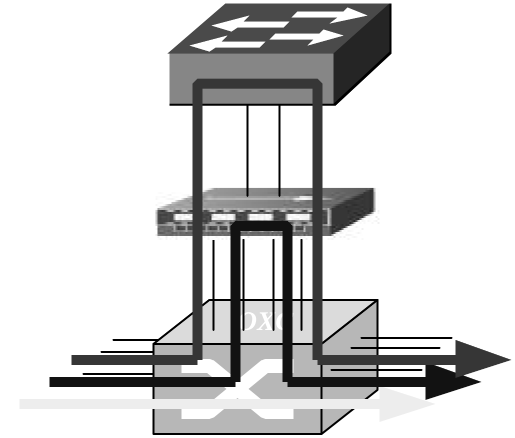
–Incorporates both QoS and resilience features of GMPLS and efficiency of Ethernet

# *Our GMPLS Testbed*

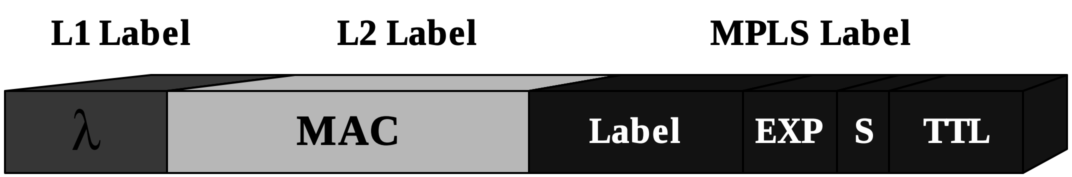
- ✓ Implements an *Integrated Reconfigurable Ethernet (layer 2) + Optical* ***Switching Layer***
  - Even with legacy Ethernet switches (routing and signaling protocols required)
  - Integrated management of the optical layer and Ethernet layer through QoS traffic engineering
- ✓ Enables *traffic grooming* 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**

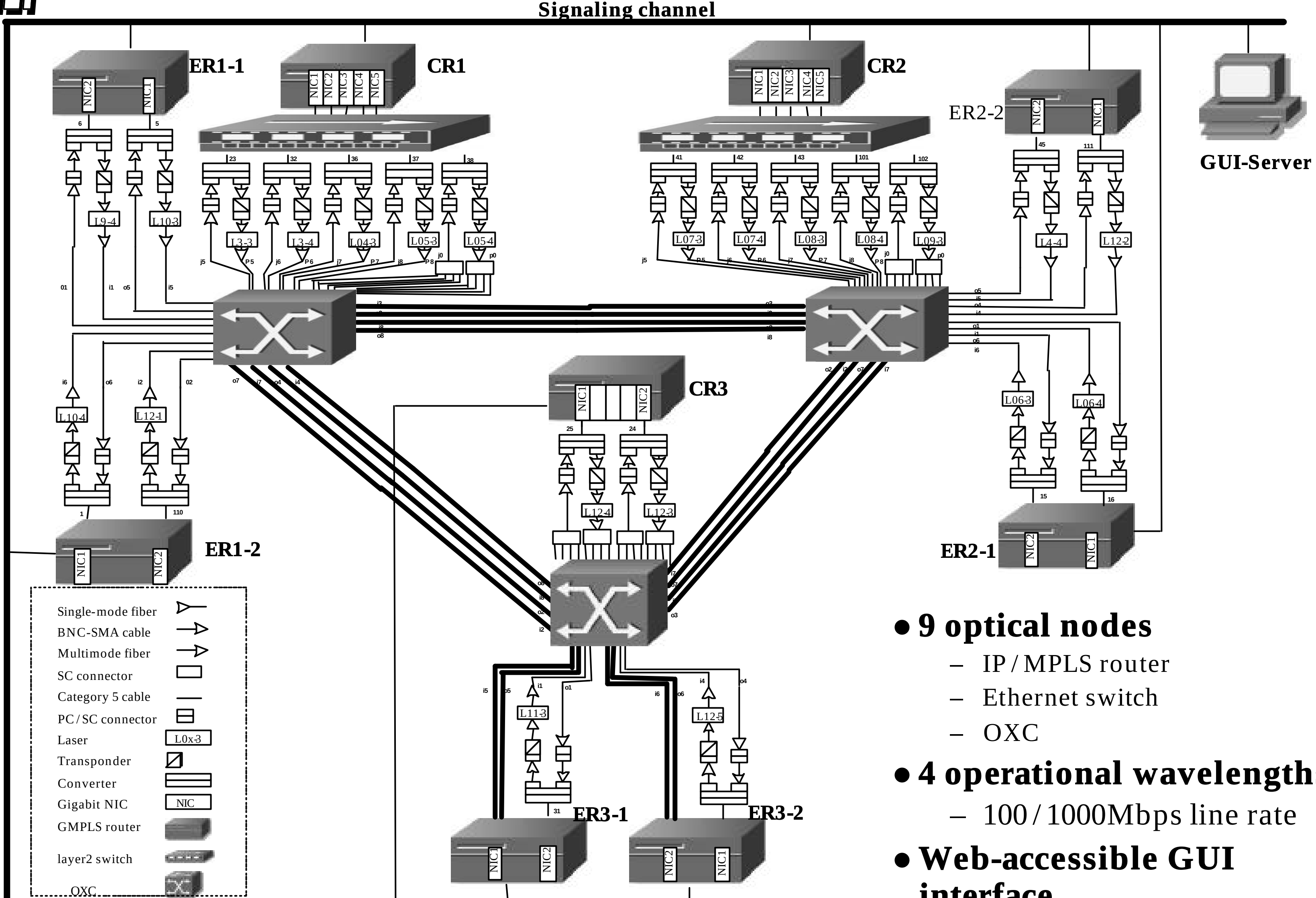
# Benefits

- 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 MPlS Testbed***

# The UMBC GMPLS Optical Testbed




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

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# *Traffic Generator and Testing Software*

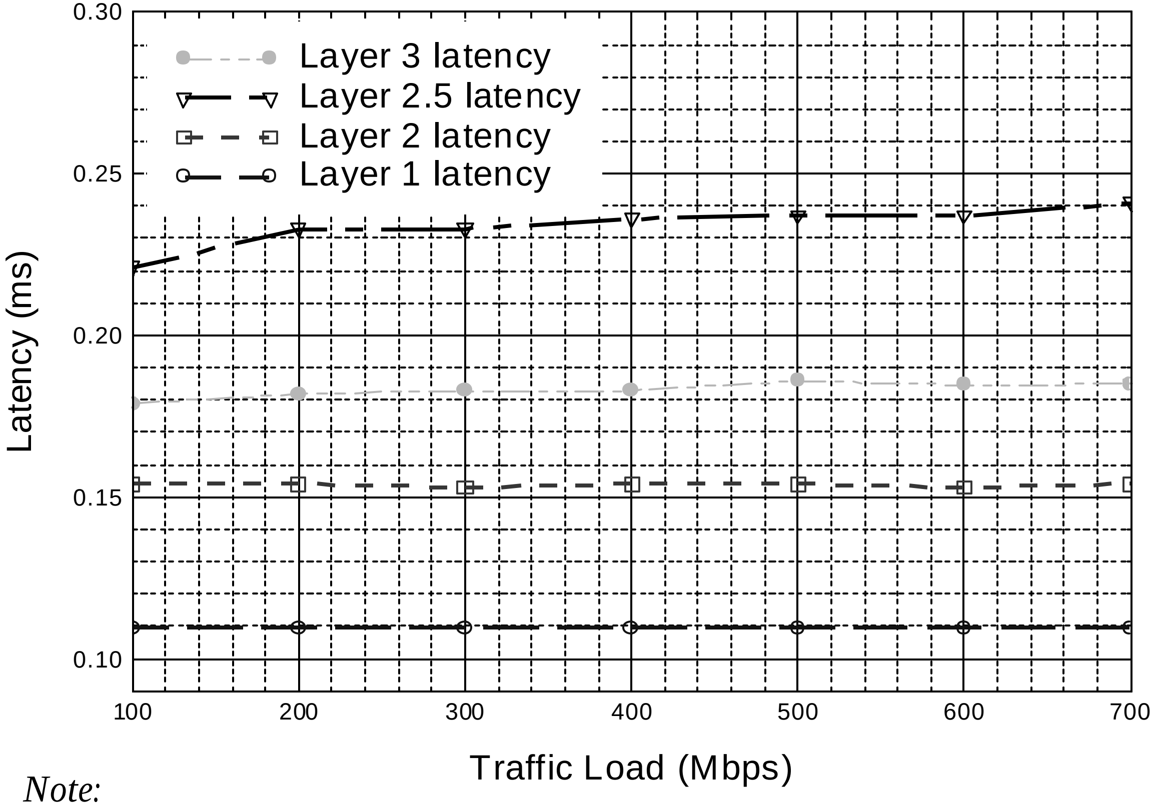
- Software: based on the 3rd party software as follows
  - Netperf
    - » Used to generate background traffic
    - » Used to randomly generate traffic
    - » Used to generate multiple user sessions
  - Iperf 1.1.1
    - » Used to test the packet drop rate (PDR), Packet Jitter, User throughput
  - 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<br>Dell SC600 | TCP STREAM | 3.51G(iperf)<br>4.1G(netperf) | 95%(iperf)<br>95%(netperf) |
| CR | TCP STREAM | 2.290G(netperf)<br>2.2G(iperf) | 98%(netperf)<br>92~96%(iperf) |
| ER3-1,ER3-2<br>ER2-2,ER2-1 | TCP STREAM | 2.231G(netperf)<br>2.2G(iperf) | 96%(netperf)<br>91~94%(iperf) |
| Client<br>Dell SC600 | UDP STREAM | 3.52G(iperf) | 93%(iperf) |
| CR | UDP STREAM | 2.33G | 83% |
| ER3-1,ER3-2<br>ER2-2,ER2-1 | UDP STREAM | 2.53M | 70% |

- Experiment setup: local loopback

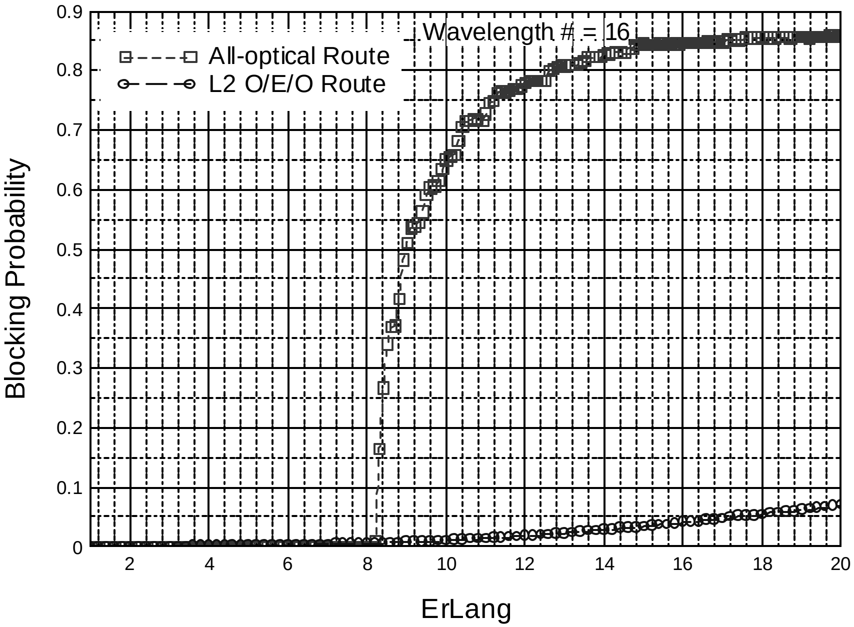
# Path Latency Reduction



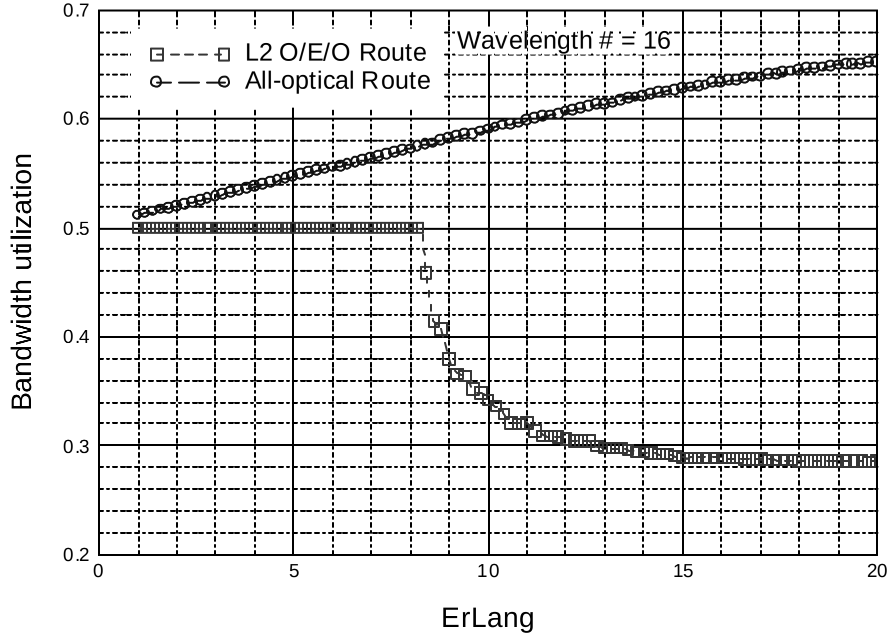

*Note:*

- 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**




**Comparison of bandwidth utilization on a single node**

*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 <=2Mbps
- All traffics are Internet best-effort traffic
- All-optical : adaptive routing and first-fit (FF) wavelength assignment
- O/E/O: standard SPF calculation

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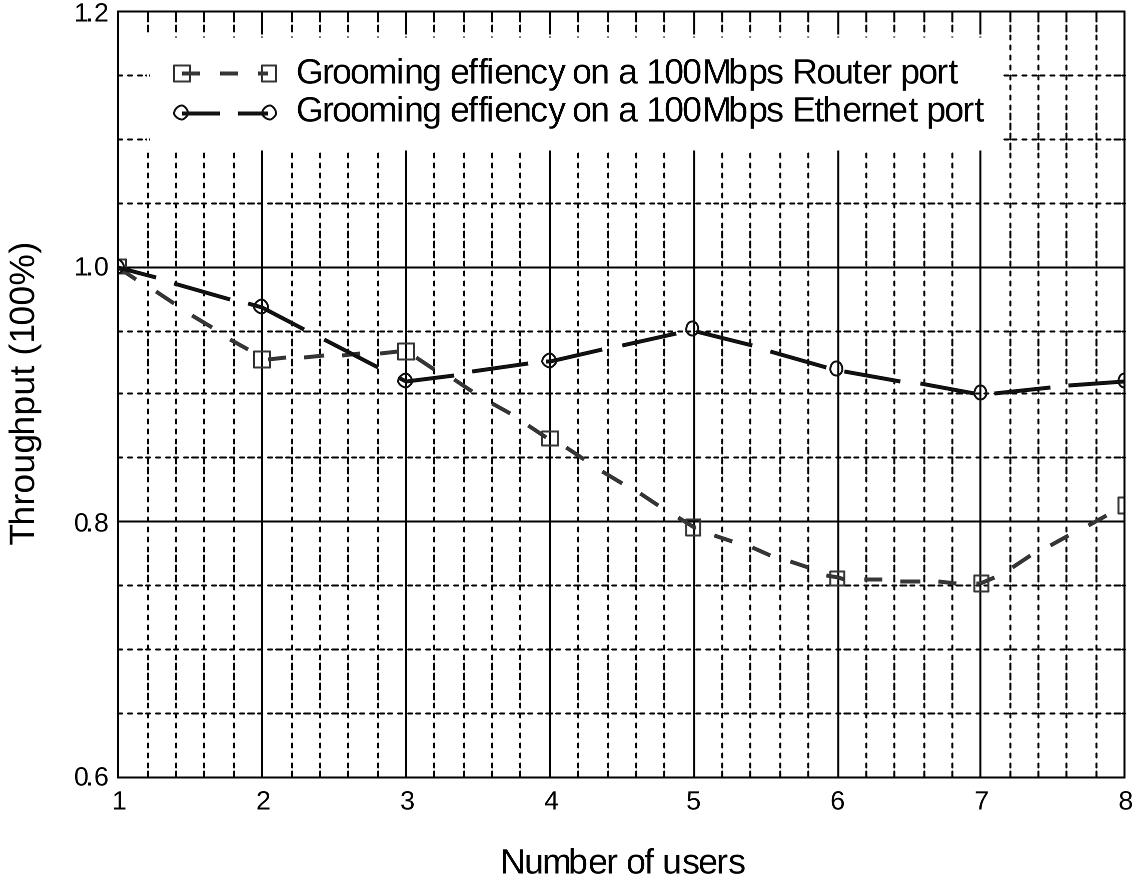
# *Efficiency of Traffic Grooming*

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- 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***

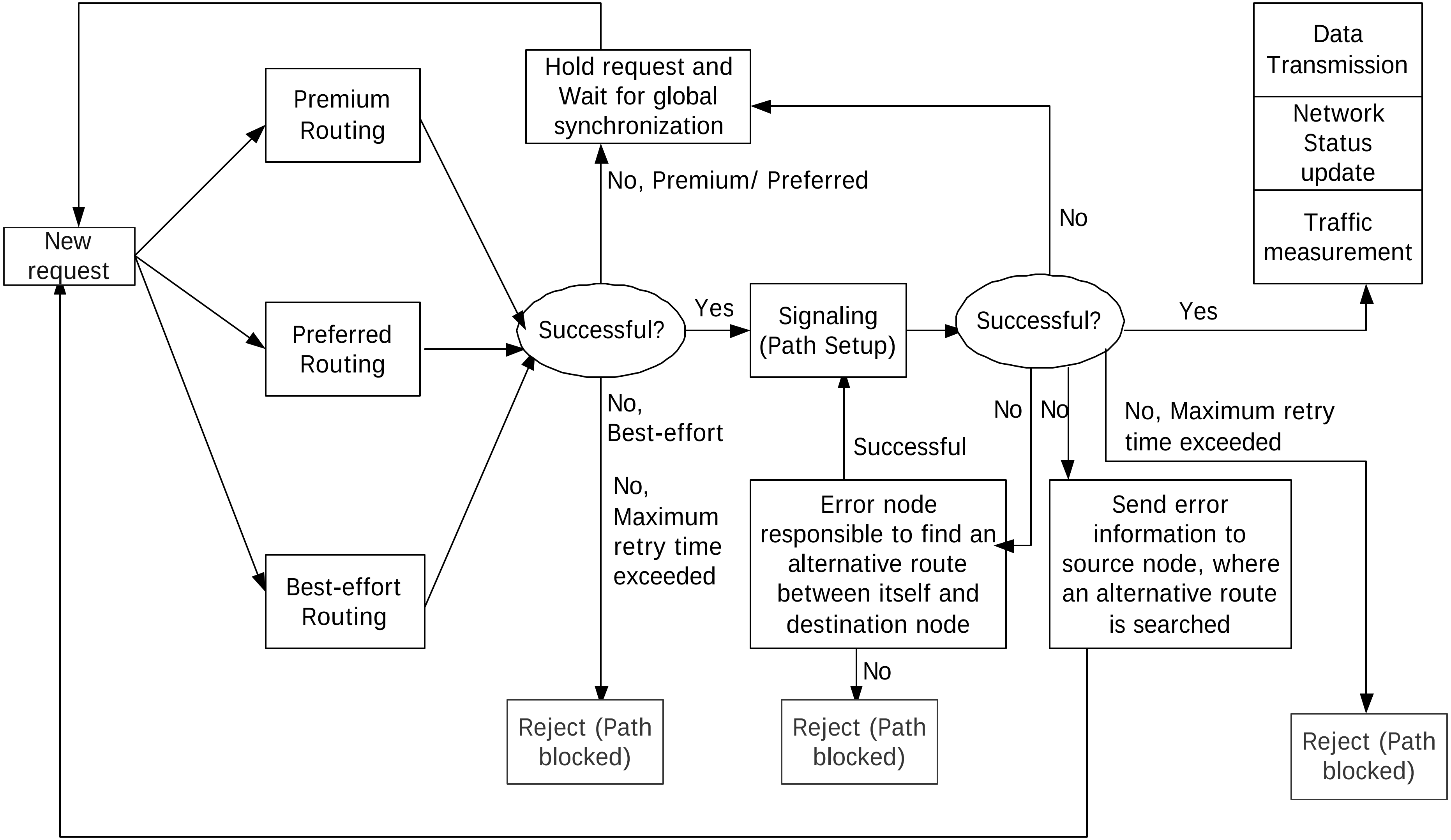
# *The Operating System Is Based On…*

- 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

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# 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

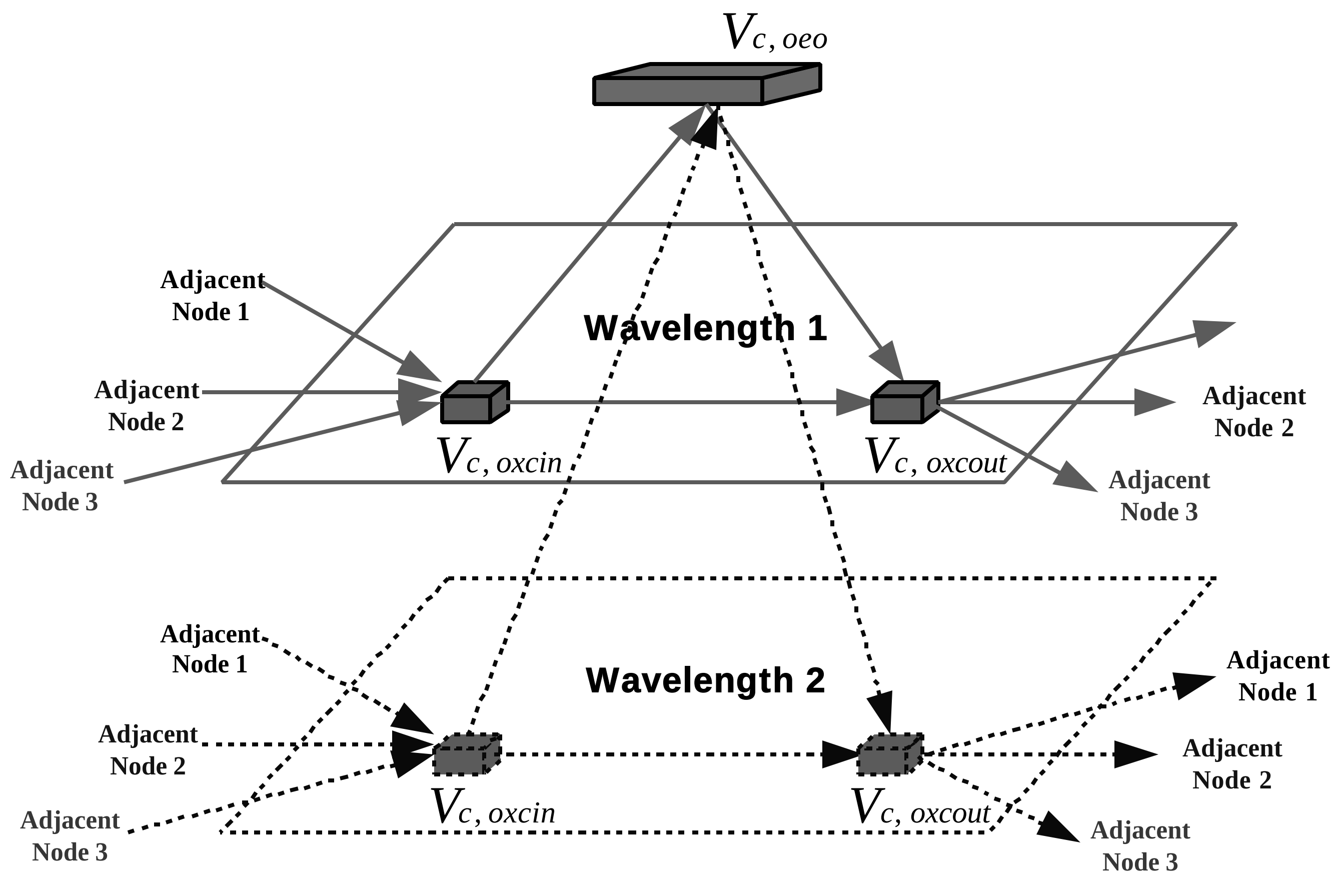
# *Routing Design*

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

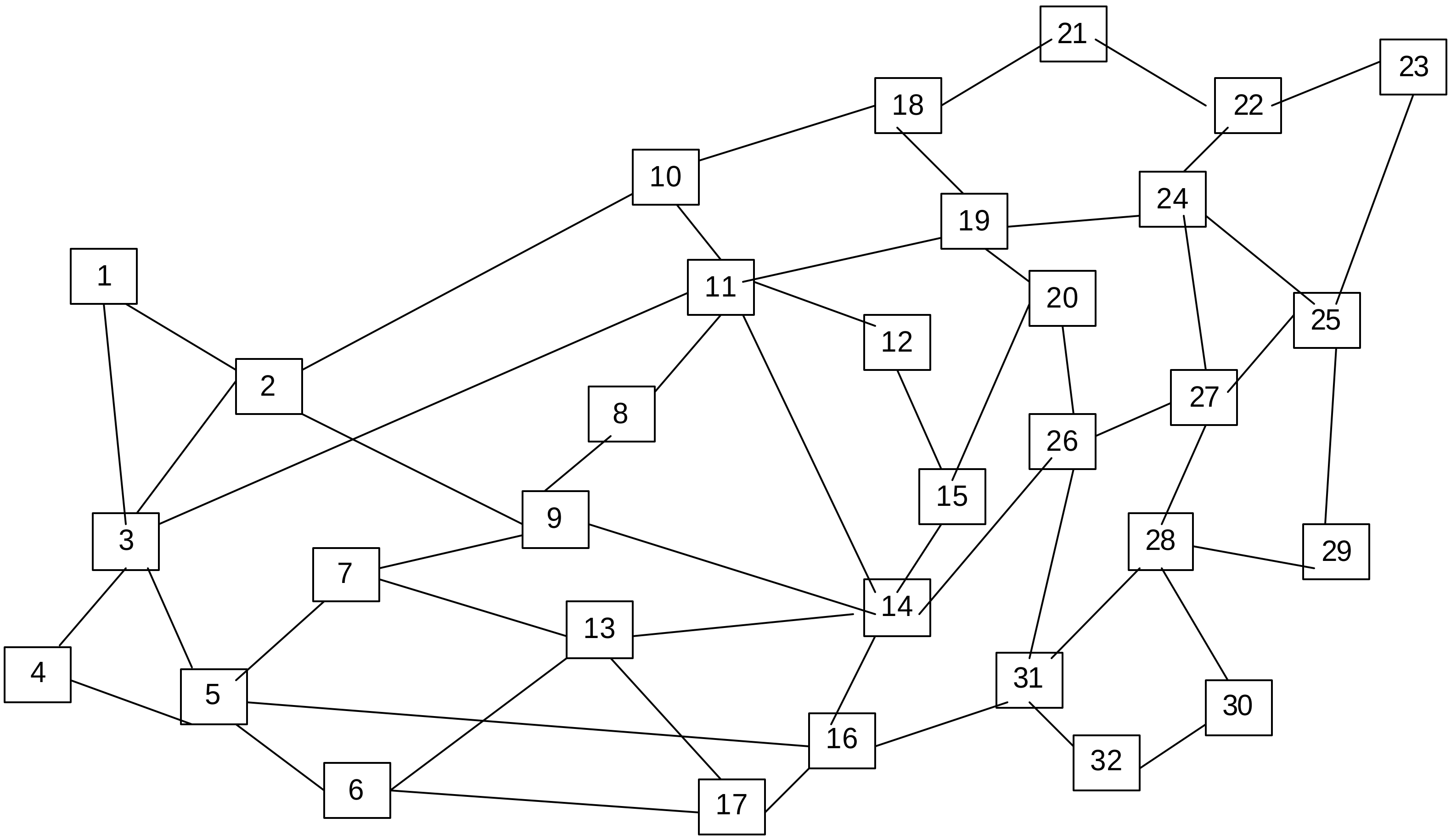


# *Routing – Sub-Problem 1*

- 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*') + delay so far <= D
  - Time complexity : O(nlog(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)
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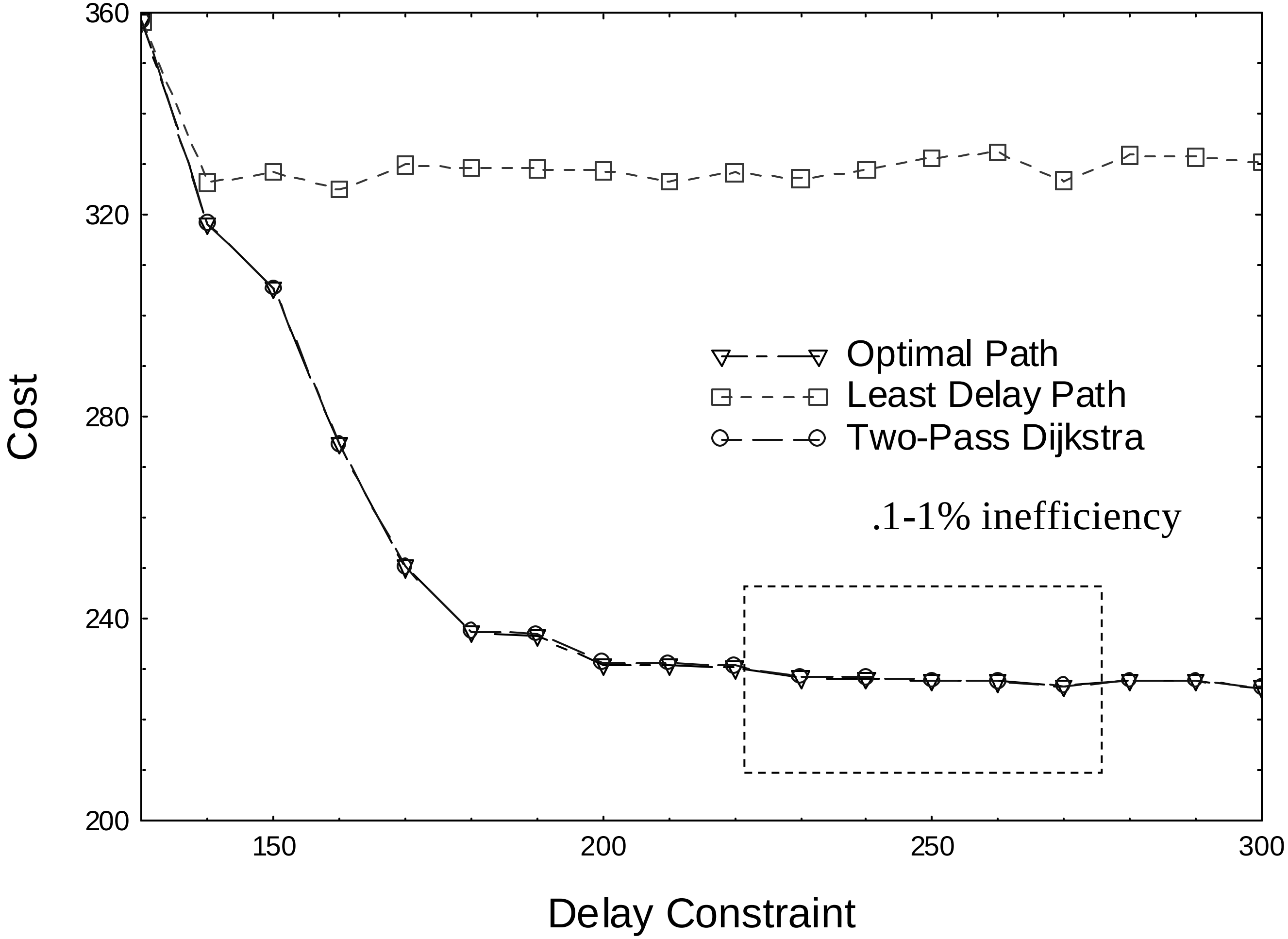

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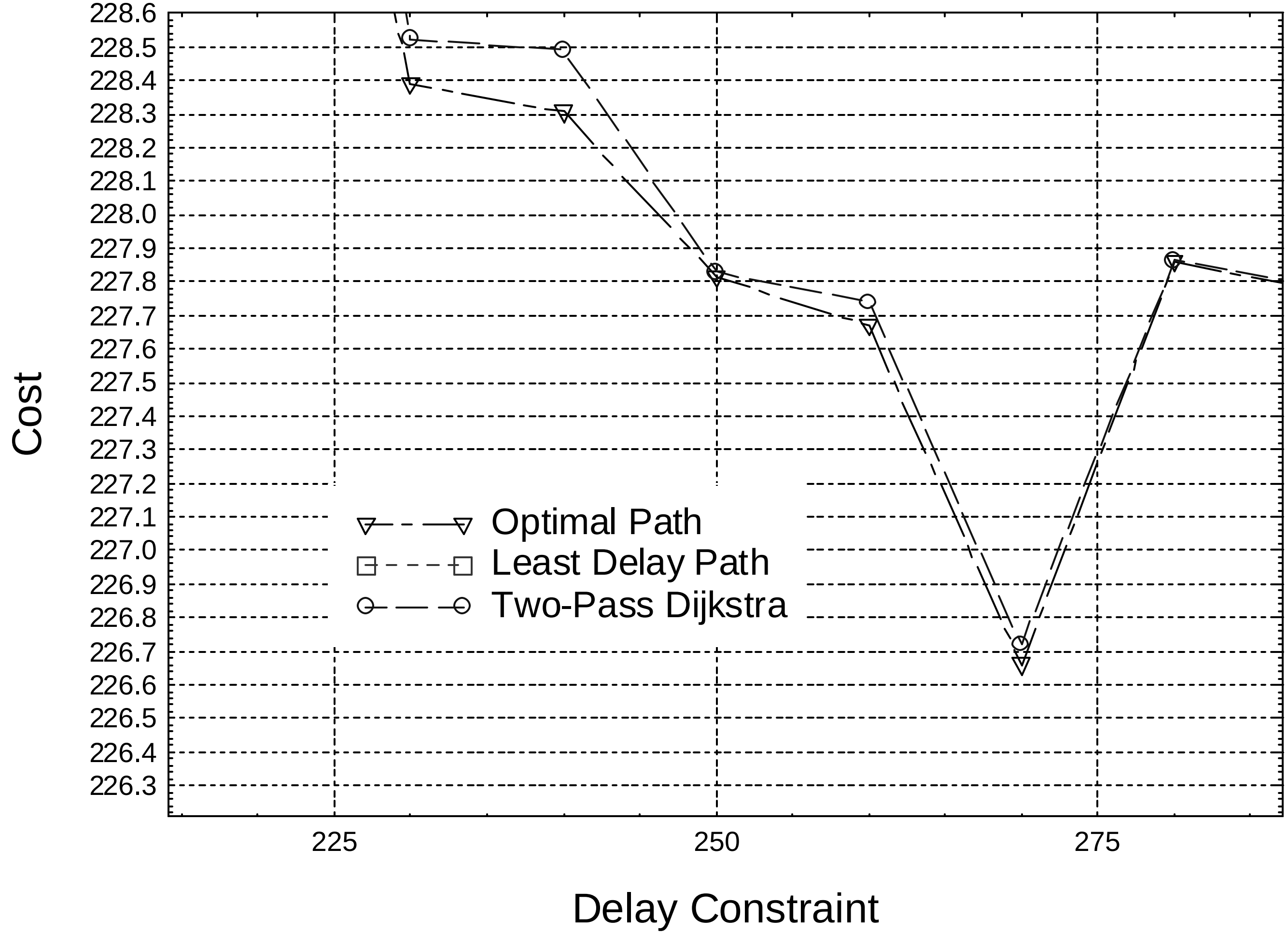


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# Conclusions

- 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