A Perspective on Photonic Multi-Protocol Label Switching

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1. **MPλS (MPLS based on WDM Lightpaths)**
   - *Implementation Issues and Challenging Problems*
2. **OC-MPLS (MPLS based on Optical Code)**
   - *Optical Implementations and Challenging Issues*
3. **Perspectives on MPλS and OC-MPLS**
   - *Advantages and Disadvantages*

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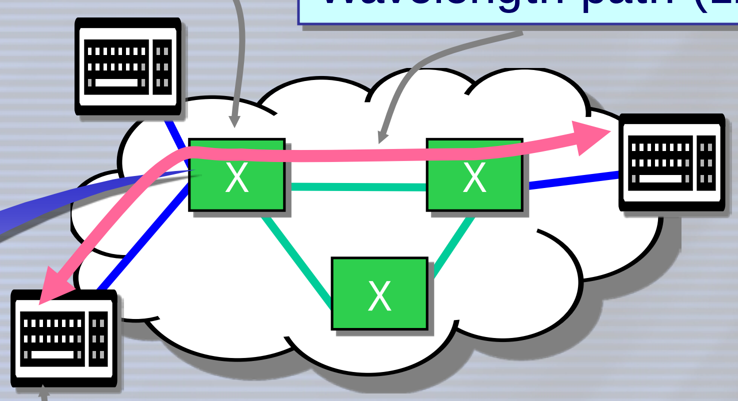
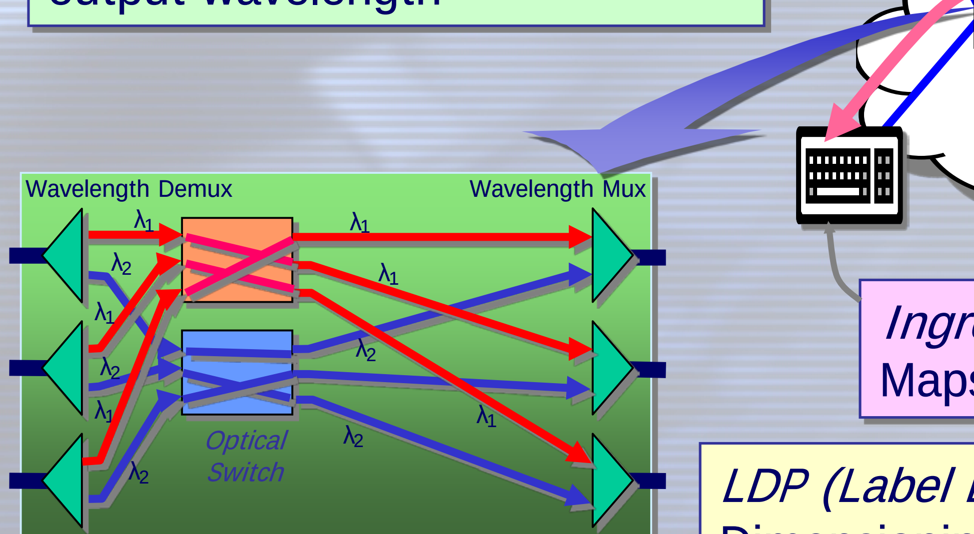
Mapping from Generic MPLS to Lambda MPLS (or GMPLS)

LSR (Label Switching Router);
Optical crossconnect directly connecting input wavelength to output wavelength

LSP (Label-Switched Path);
Wavelength path (Lightpath)





Optical Crossconnect

Ingress LSR;
Maps from IP address to lambda

LDP (Label Distribution Protocol);
Dimensioning by wavelength and routing assignment algorithm

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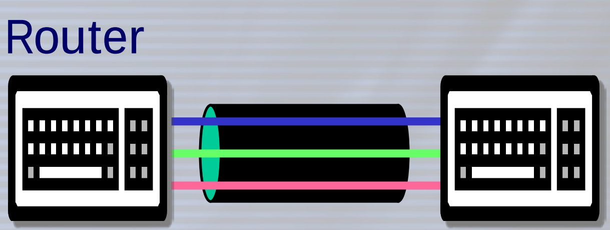
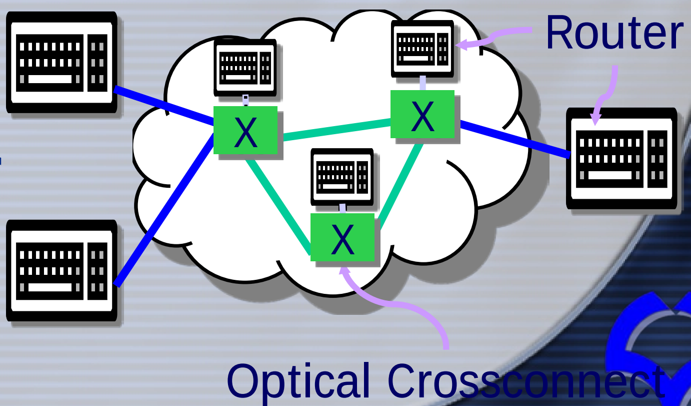
Photonic Internet Architecture

- *Four Kinds of Architecture*

1. **WDM link network**
   - **Connects adjacent routers by WDM (multiple wavelengths increase the bandwidth)**

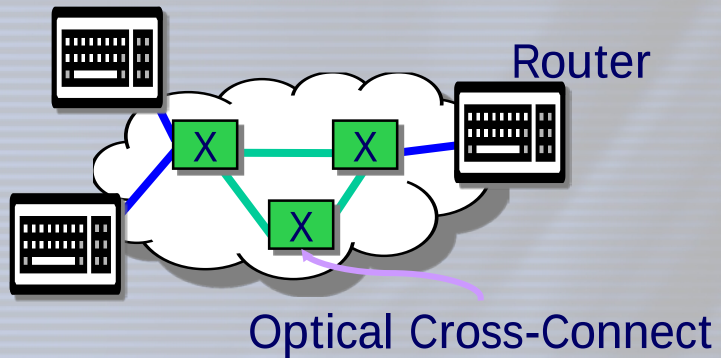


2. **WDM path network**
   - **Cut-through techniques for IP packets on established path provided by the underlying networks**

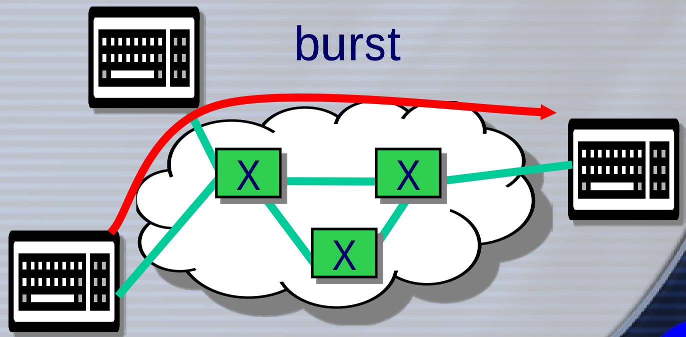


Photonic Internet Architecture (Cont'd)

3. **WDM Path Network**
   - Lambda switching by MPLS technology (MPλS or GMPLS)

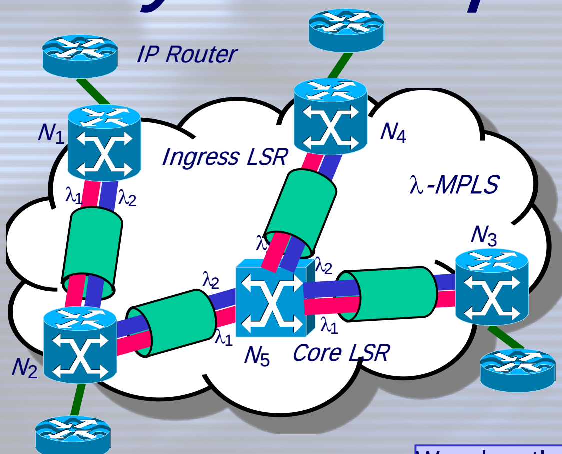


4. **WDM Packet-switched Network**
   - E.g., burst switching by routing and wavelength assignment (RWA) on demand basis

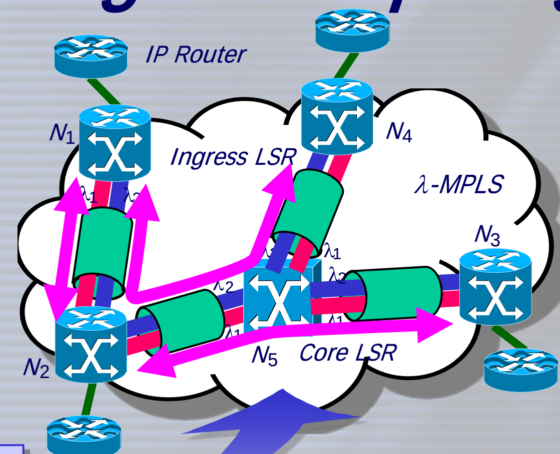


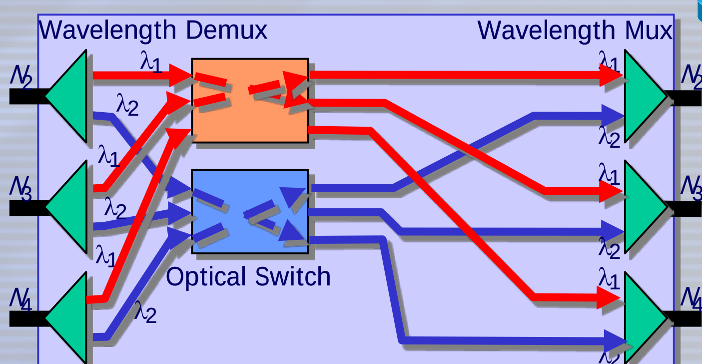
Logical Topology by Wavelength Routing

- *Physical Topology*



- *Logical Topology*

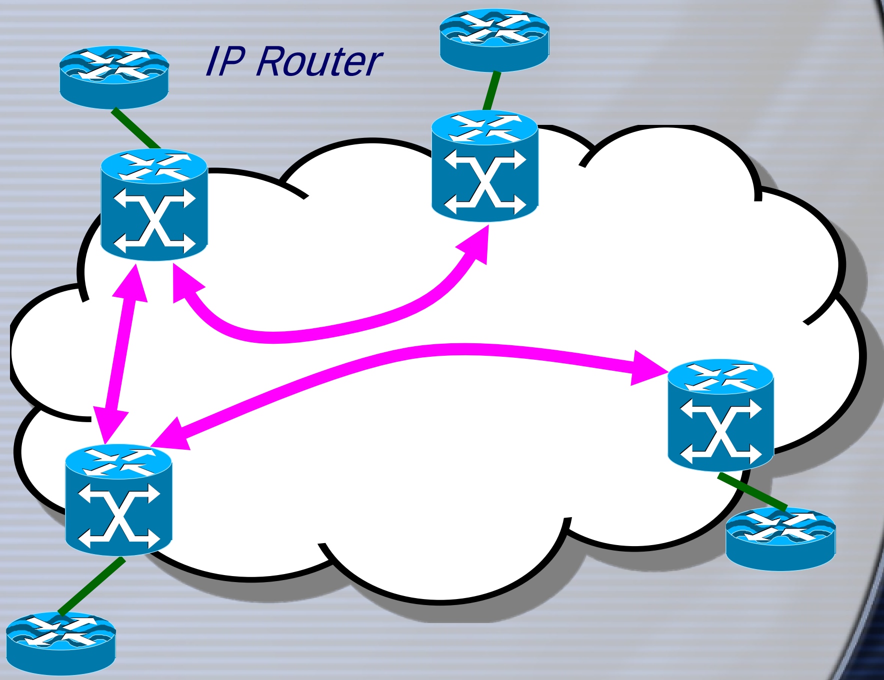




Optical Cross-Connect

Logical View Provided to IP

- Redundant Network with Large Degrees
  - Smaller number of hop-counts between end-nodes
  - Decrease load for packet forwarding at the router
  - Relief bottleneck at the router

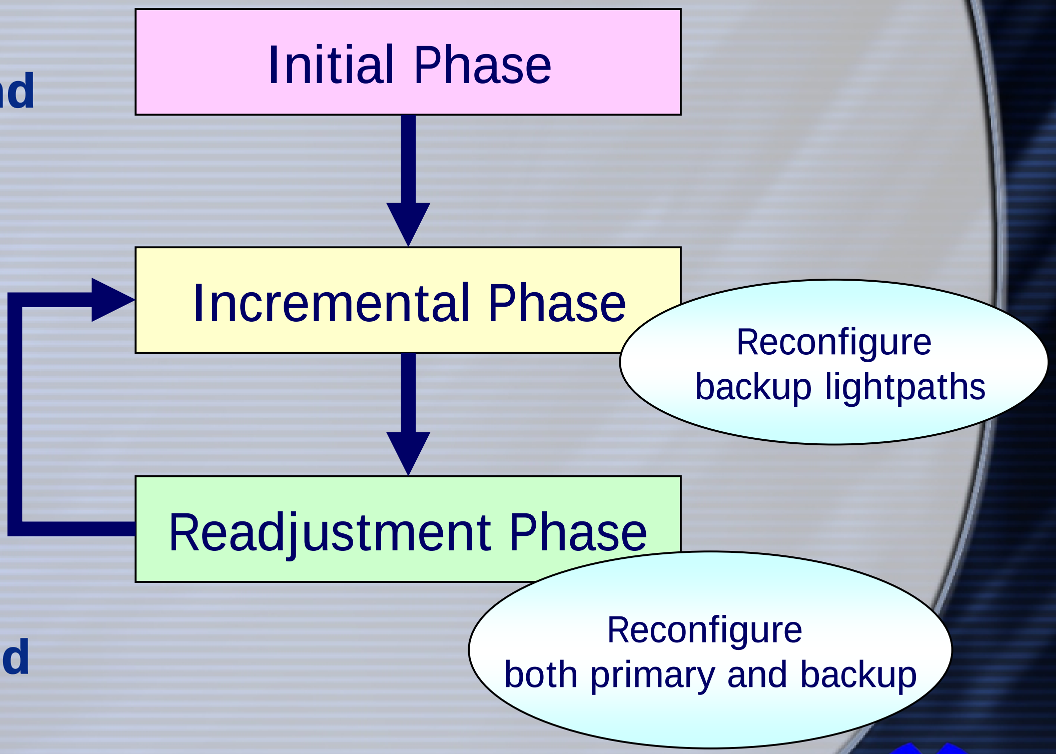


Challenging Problems of MPλS

- *Logical Topology Design Issues*
  - Past researches assume the traffic matrix is given
  - Objective is maximization of wavelength utilization or minimization of the required # of wavelengths
  - Optimization problem is then solved by LP or heuristics
- *Bottleneck at Ingress Nodes*
  - Bottleneck is shifted to the Ingress Nodes requiring electronic processing
- *Survivability*
  - IP and WDM Functional Partitioning or Integration

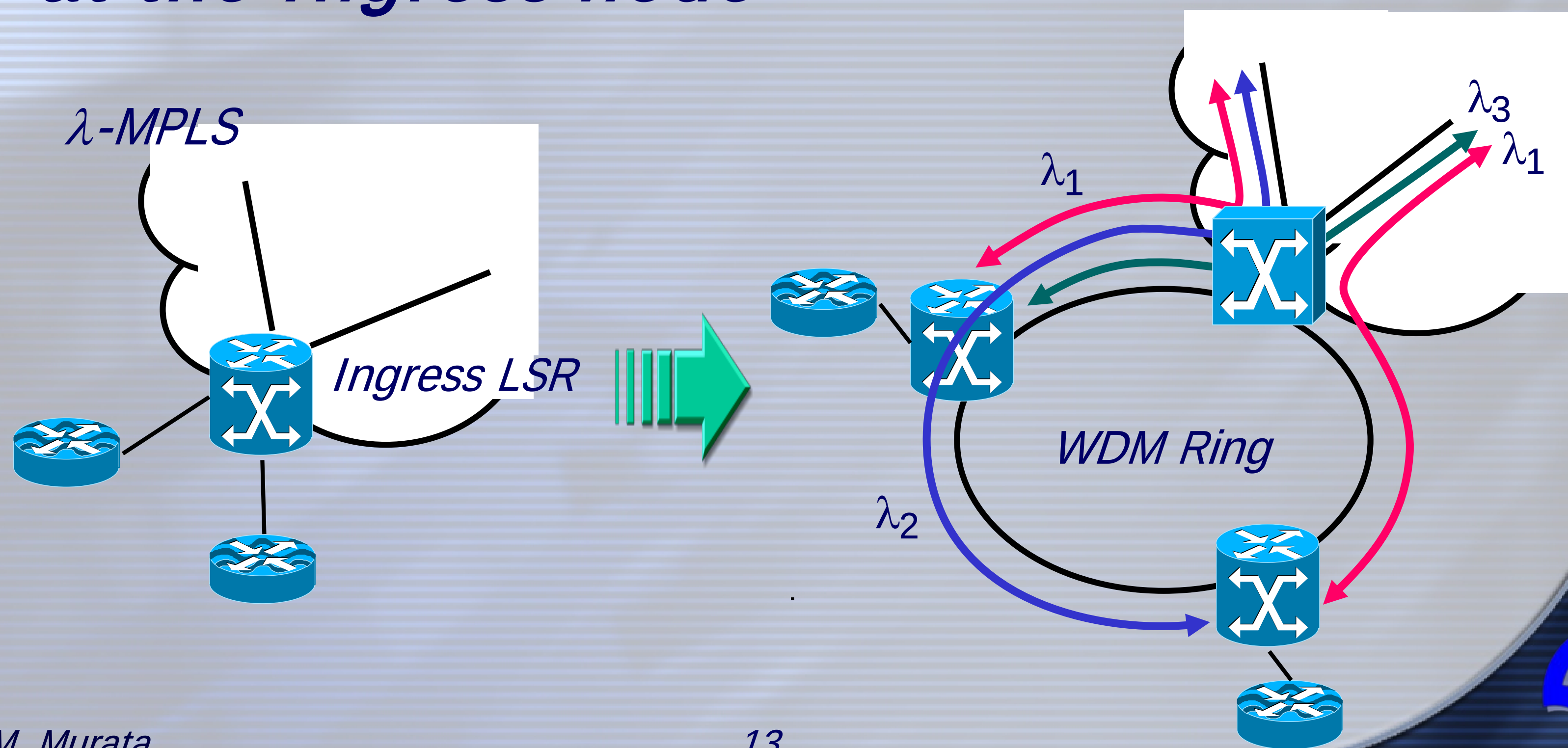
Incremental Capacity Dimensioning Approach

- *Initial Phase*
  - Design Logical topology with given traffic demand
- *Incremental Phase*
  - primary lightpath is incrementally setup
  - reconfigure backup lightpaths
- *Readjustment Phase*
  - All of the lightpath (including primary lightpath) is reconfigured

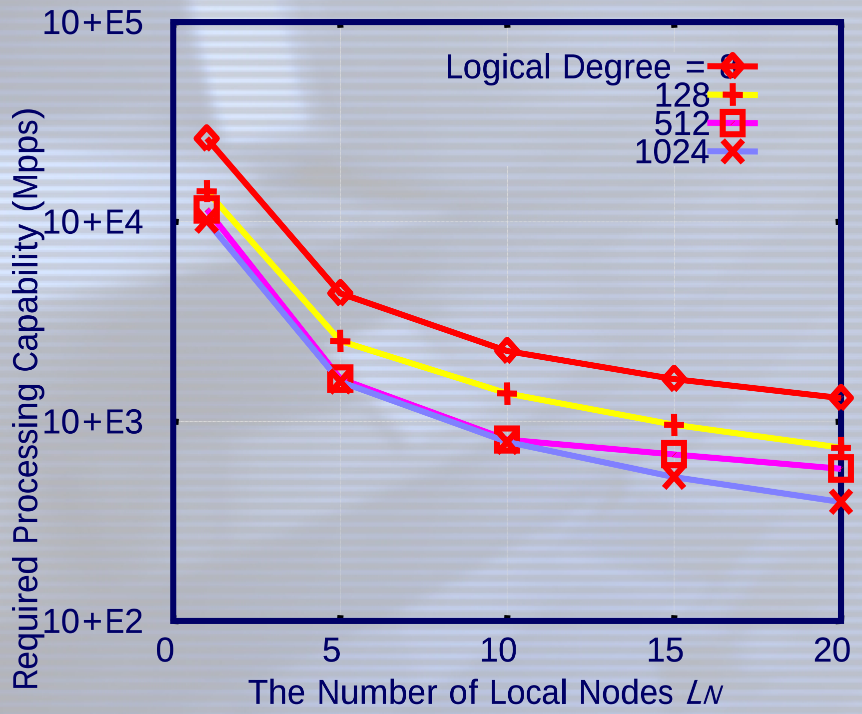


Traffic Load Distribution by WDM Ring

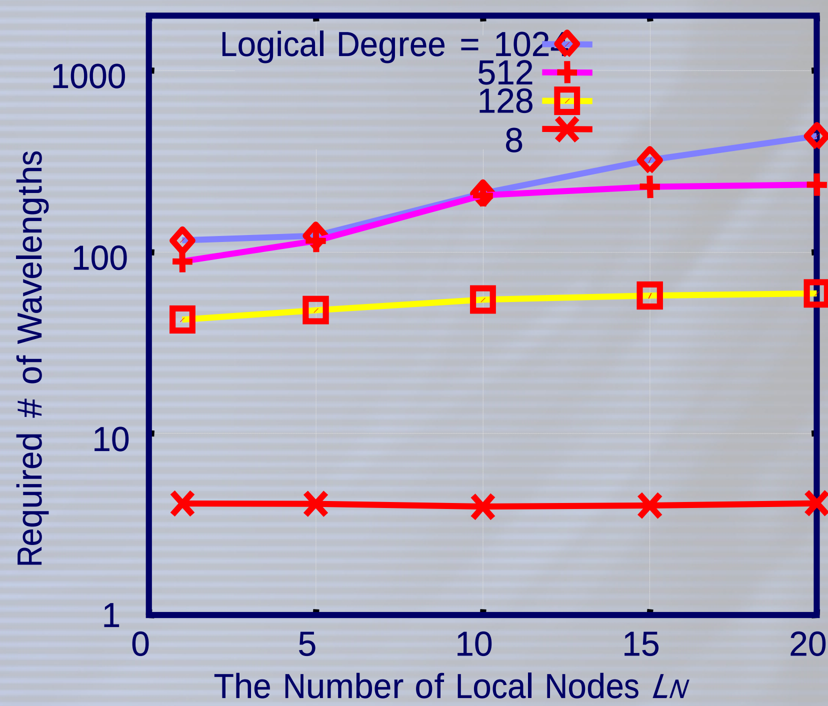
- *Distribute the traffic load by WDM ring at the Ingress node*



Effects of Introducing WDM Ring



Packet Processing Rate Required at Router



Required Number of Wavelengths

Do We Need More "Intelligent" WDM Network?

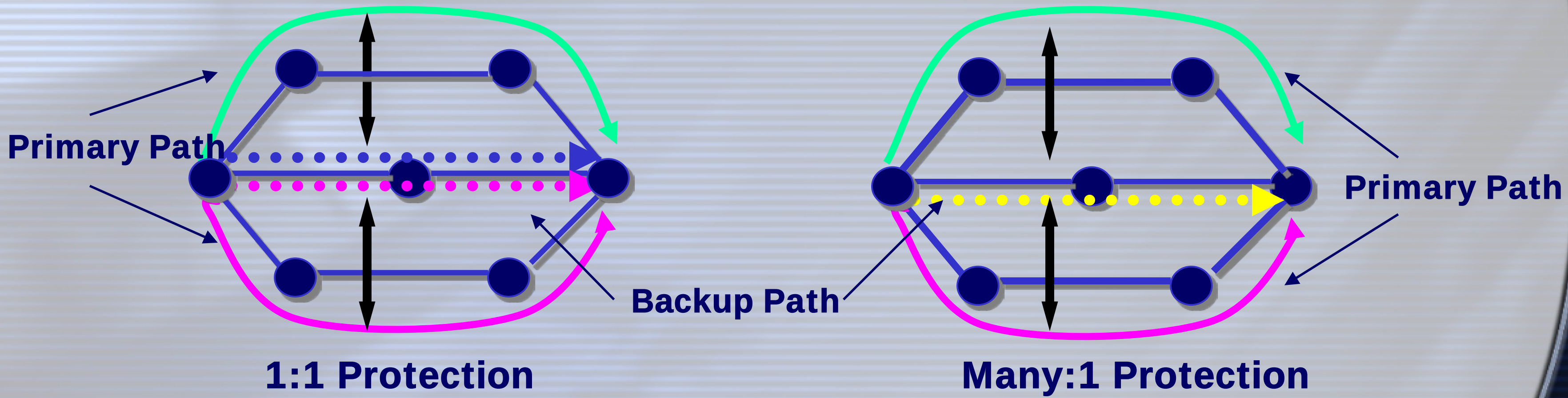
- *WDM network itself has network control capabilities*
  - **Routing function**
    - **IP also has it!**
  - **Congestion control function**
    - **TCP also has it!**
    - **TCP over ATM (ABR service class) is difficult to work well Parameter tuning of control parameters in ABR is not easy**
  - **Connection establishment**
    - **IP is connectionless**
    - **Multimedia application does not require 10Gbps channel**
  - **Multi-layered Functionalities?**
- *Important is reliability*

Functional Partitioning between IP and WDM?

- *Reliability functionalities offered by two layers*
  - **IP Layer: Routing**
  - **WDM Layer: Path Protection and Restoration**
- *WDM should provide its high-reliability mechanism to IP*
  - **Protection mechanism**
    - **link protection**
    - **dedicated-path protection**
    - **shared-path protection**
  - **Network dimensioning is important to properly acquire the required capacity of IP paths (traffic glooming)**
    - **Reconfiguration mechanism of logical topology by wavelength routing**

WDM Protection

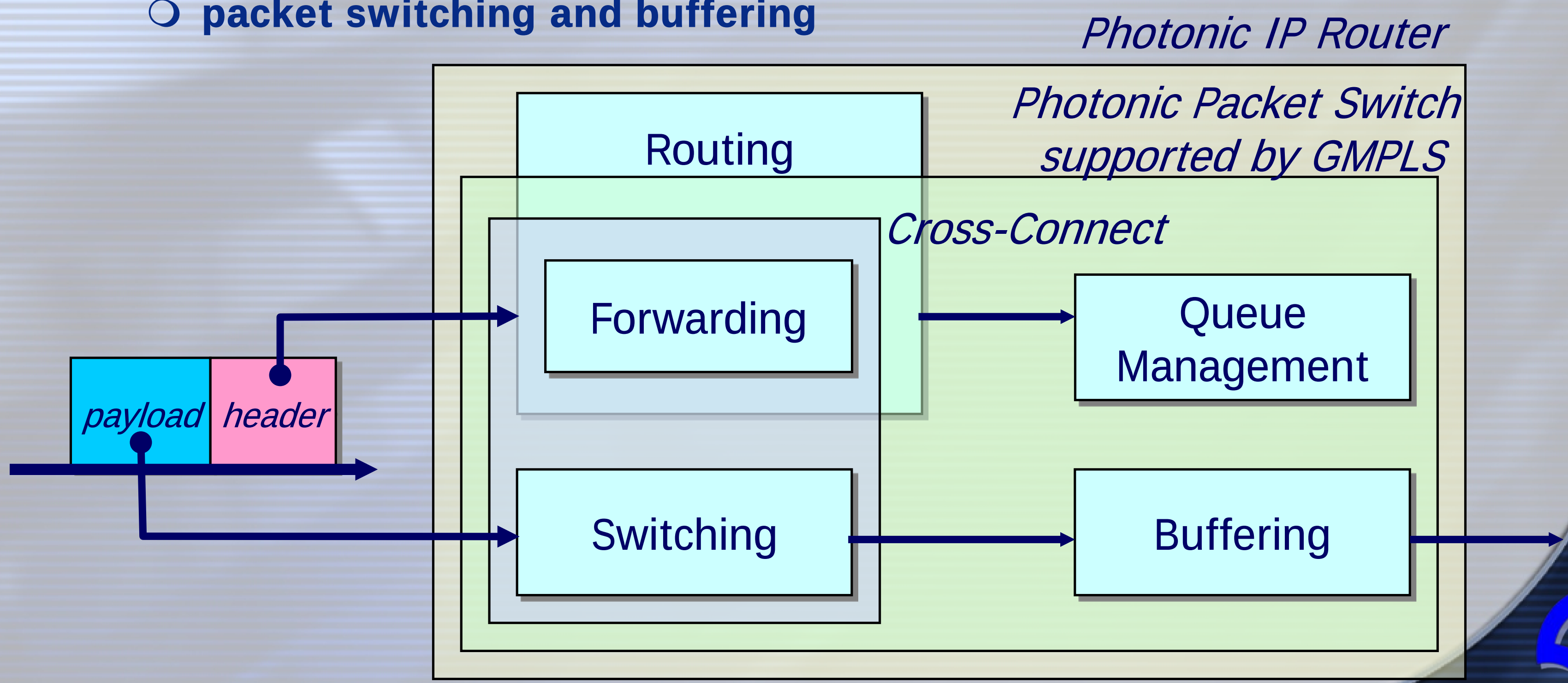
- *Immediately switch to backup path on failure of nodes/links*
  - In the order of 10ms
- *1:1 Protection vs. Many:1 Protection*



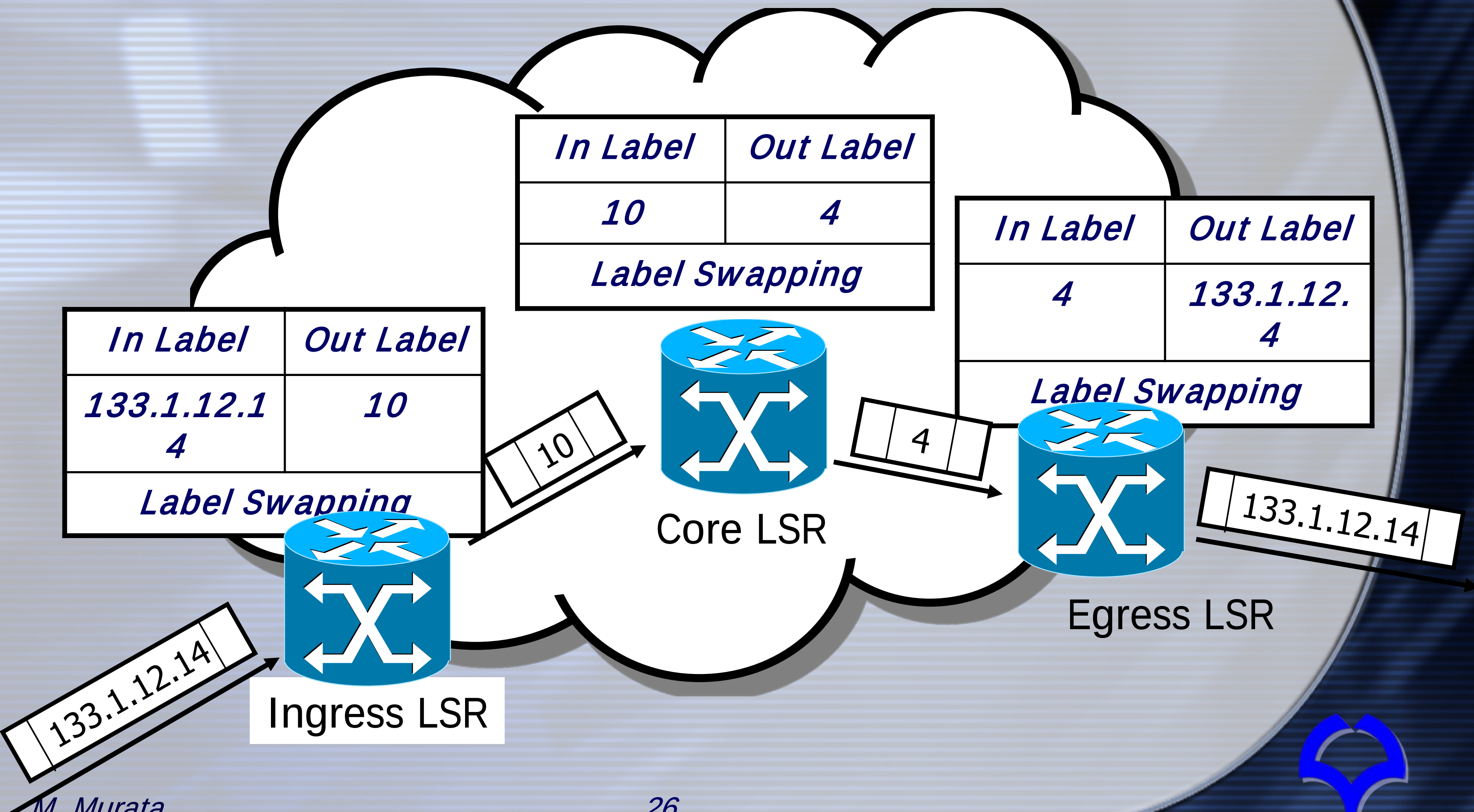
- *Protection technique suitable to IP over WDM network?*
  - IP has its own protection mechanism (i.e., routing) while it is slow
  - We want an effective usage of wavelengths
  - Many:1 protection is reasonable

Cross-Connect, Switch and Router

- *Photonic switch within MPLS requires*
  - **packet forwarding based on "label"**
  - **queue management based on "label"**
  - **packet switching and buffering**



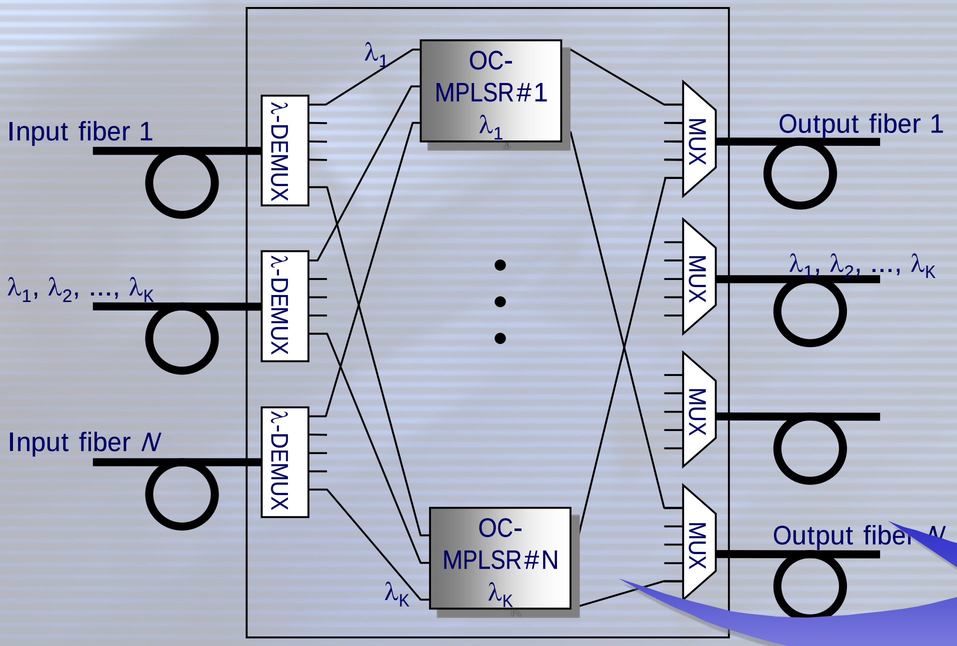
Label Swapping in MPLS



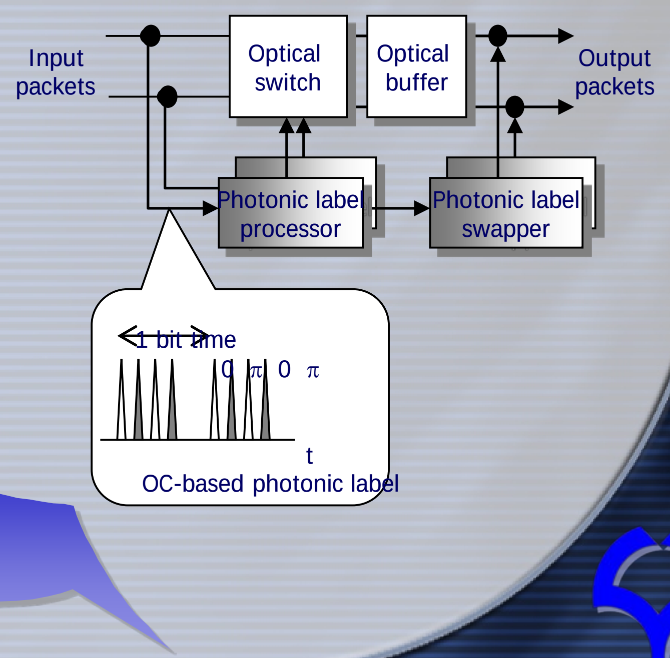
Optical Code based MPLS

- *Photonic label based on optical codes*

OC-based Switching Node

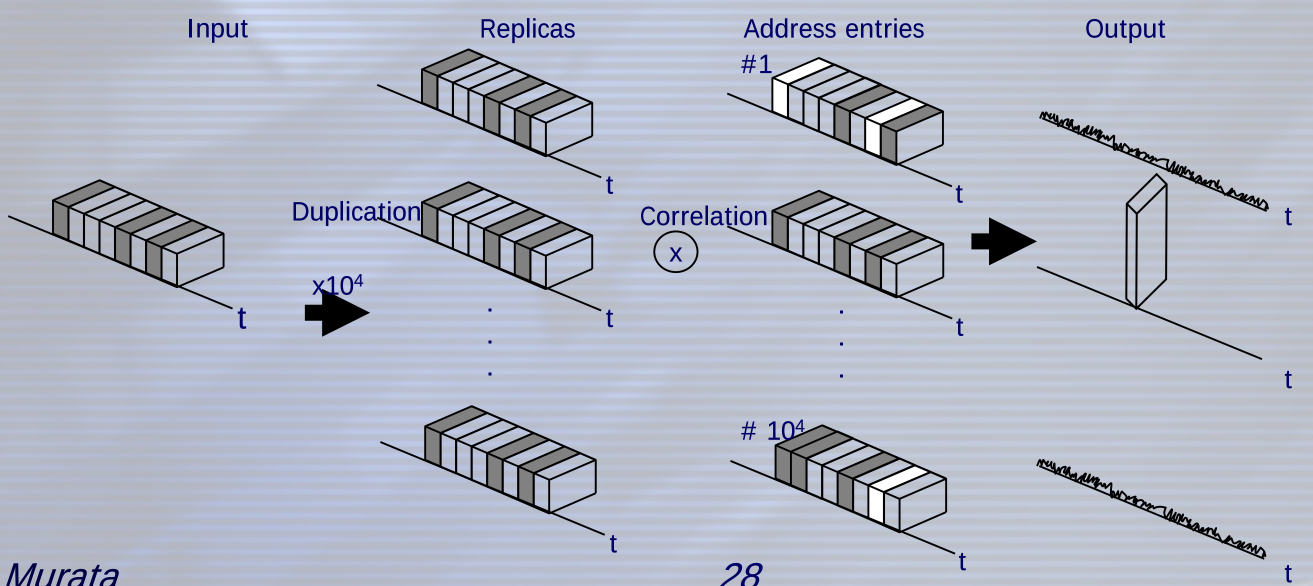


OC –based Switch

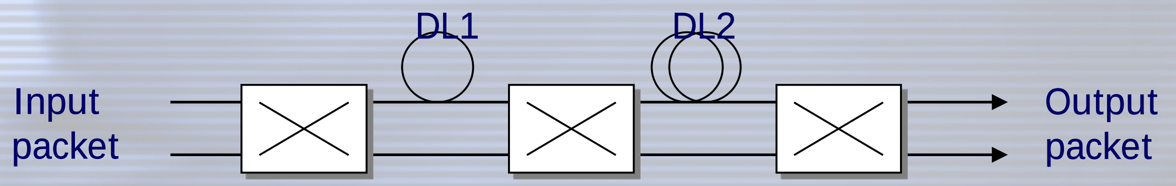


Photonic Label Processing

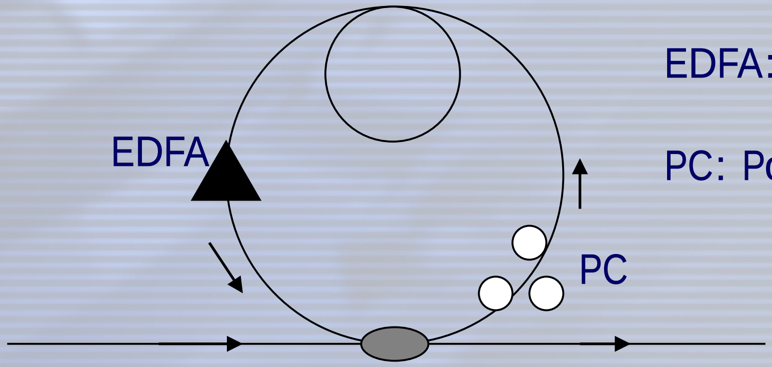
- *Optical code by BPSK*
- *Photonic label processing in optical domain*
  - **photonic label is tapped from packet header**
  - **optically dupilcated by optical amplification**
  - **power-splitted as many copies as the count of label entries in the table**
  - **optical correlations between the copies and the label entries is performed in parallel**



Implementations of Optical Buffers by Delay Lines



(a) Multi-stage switched delay line buffer



EDFA:Erbium doped fiber amplifier
PC: Polarization controller

(b) Re-circulating loop buffer

Photonic Packet Switch for Asynchronously Arriving Variable Packets

- ***Buffer Scheduling***
  - **Delayed Line Buffer**
- ***Variable-Length Packets***
  - **Counter for Buffer State; b_{ij} for output line j on wavelength i**
  - **For each arrival of packet with length x**

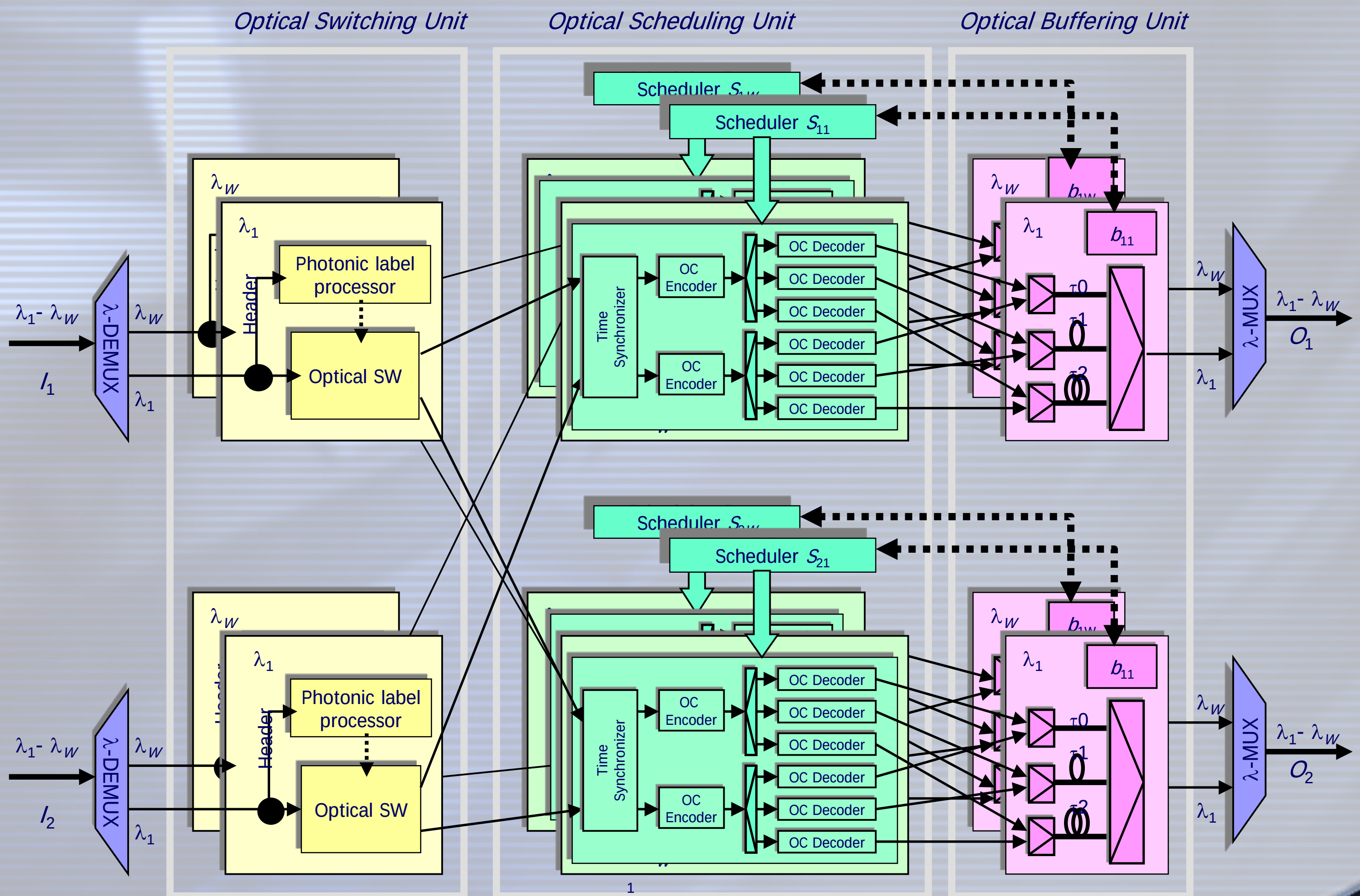
$$b_{ij} \leftarrow b_{ij} + \lceil x / D \rceil$$

For each delay unit D

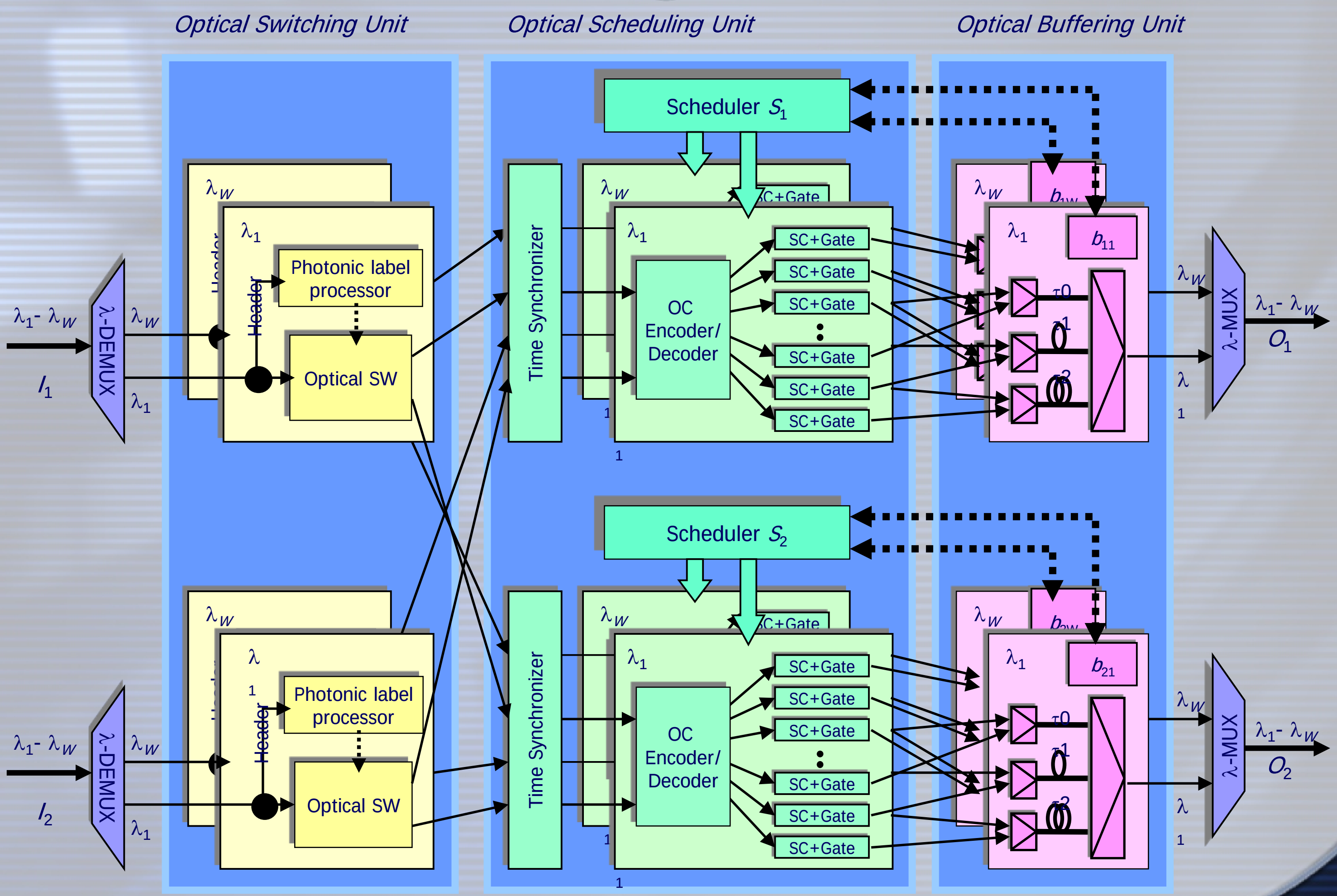
$$b_{ij} \leftarrow b_{ij} - 1$$

- ***For asynchronous arriving***
  - **Introduce packet sequencer**

Structure of OC-based Photonic Packet Switch Without Wavelength Conversion



Structure of OC-based Photonic Packet Switch With Wavelength Conversion



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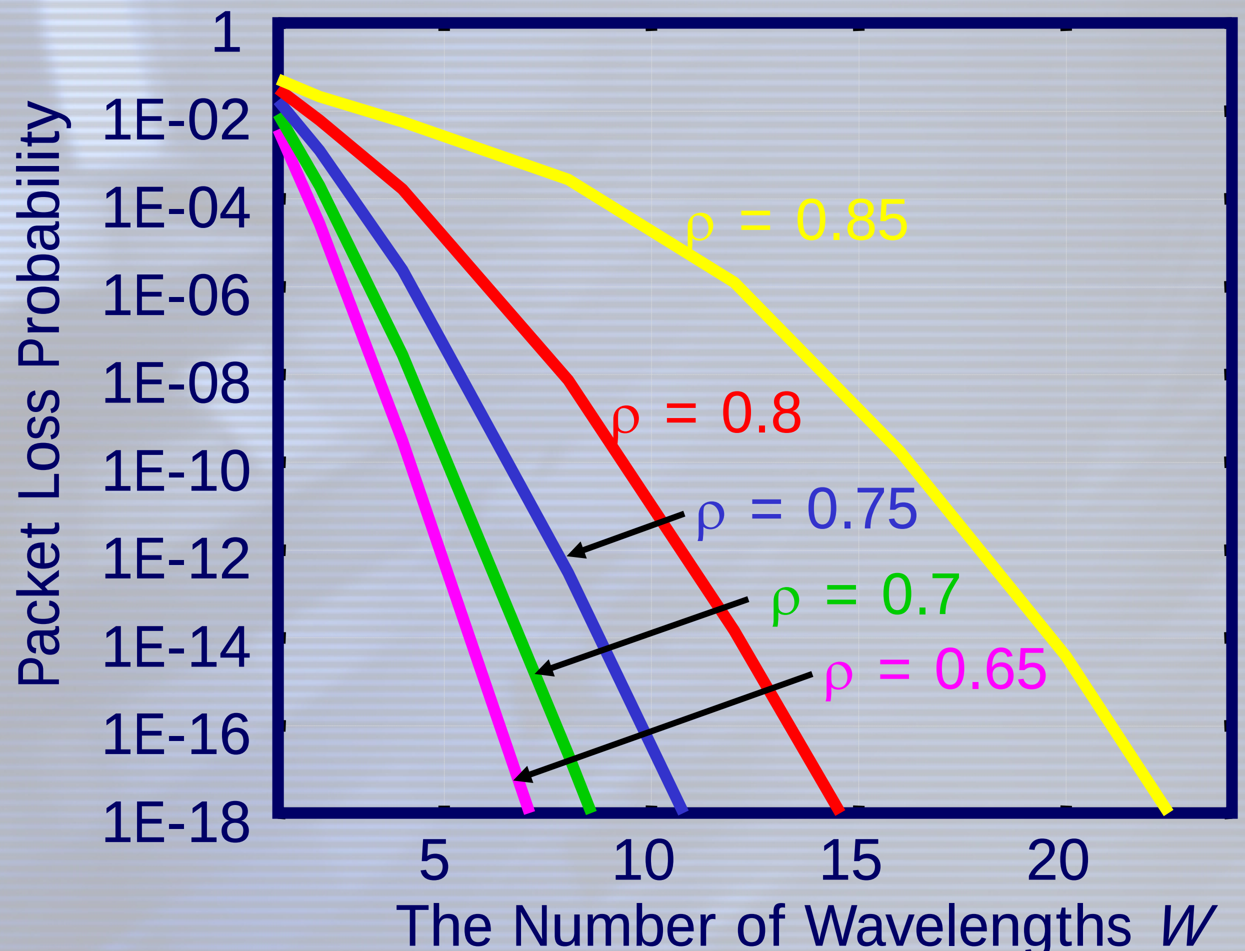
Performance of Proposed Switch



Problems of MPλS

- *The incremental capacity dimensioning is infeasible in the current logical topology design approach*
  - **Network performance is heavily dependent on the logical topology design approach**
- *Unit of Path Granularity is Wavelength Capacity*
  - **too large to accommodate the end-to-end traffic**
  - **The capacity increase per each wavelength does not alleviate the problem**
  - **The increase in the number of wavelengths may help it. However, it requires the large-scaled of, e.g., 1,000x1,000 optical cross-connect**
- *Flow aggregation at the Core LSR cannot be expected*
  - **The label exchange within the network poses the wavelength change at an optical node**

Advantages of OC-MPLS

- *The granularity is "packet"*
  - **Allows a flexible network structure**
  - **Simplified packet switching can offer large capacity in the optical domain**
  - **An ATM-based MPLS protocol suite can be applied**
  - **Traffic engineering developed for MPLS is also utilized.**
- *OC-MPLS is capable of merging of packets by introducing optical buffering*
  - **Attains an ultimate bandwidth efficiency**
  - **MPλS is unable to realize it due to the coarse granularity.**
- *The length of OC photonic label could be flexible*
  - **The longer label could be used as the network layer header of the packet**
  - **Can be used both to assigned multiple flows from IP prefix to application-level flow**
  - **Possible to offer QoS-enabled services**
  - **Optical codes are not only applicable to the exact match algorithm in the OC-MPLS but also applicable to the longest prefix match, and hence OC-based destination-based IP routing might be realizable.**

Remaining Problems of Establishing OC-MPLS

- *The switch fabric, constructed with photonic space switch and photonic buffer, has to be optimized to achieve the desired performance*
- *Statistical multiplexing would work well by very huge bandwidth provided by OC techniques even if the packet buffer capacity is not large. However, a further research on the traffic engineering approach of MPLS is necessary under the conditions that the bandwidth is very large, but the packet buffer size is small.*