Facultat d' informàtica de Barcelona

Departament d'Arquitectura de Computadors

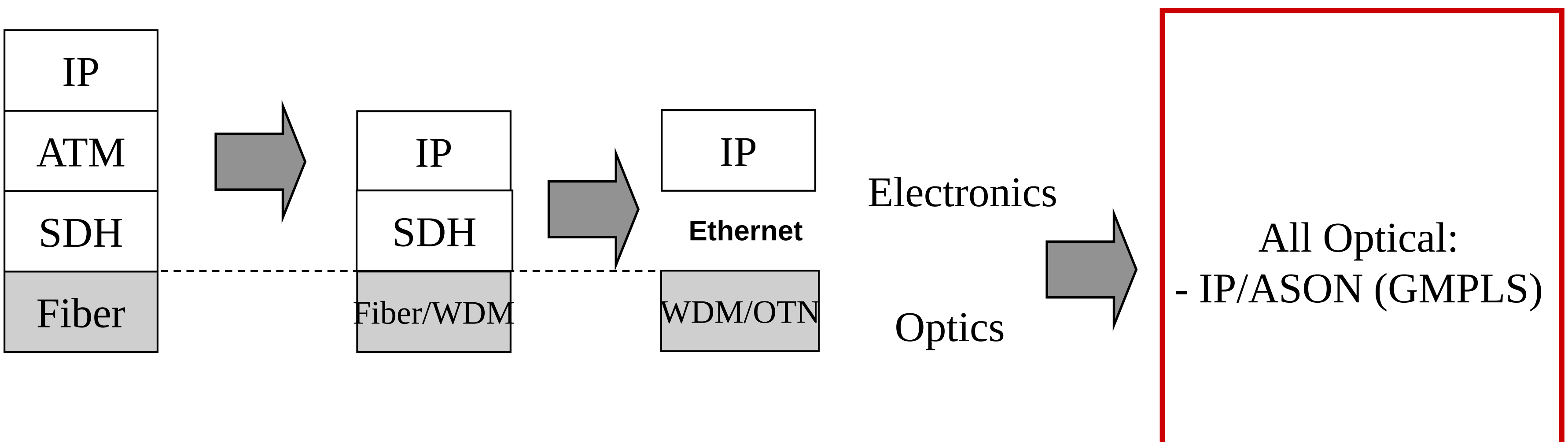
UNIVERSITAT POLITÈCNICA DE CATALUNYA

# *IP Transport Networks*

The Transport Network concept
The Control Plane concept
MPLS: MultiProtocol Label Switching
GMPLS: Generalized MultiProtocol Label Switching

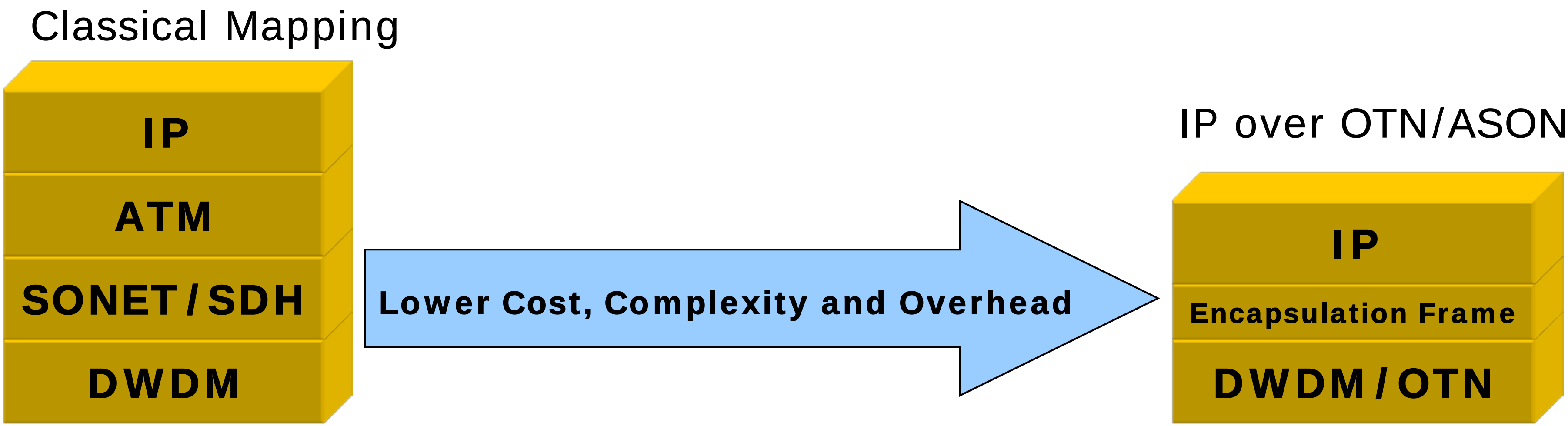
# Network Technologies for Supporting IP

- Flatting the IP/ATM architecture:
  - IP/SDH
- Migrating the Internet backbone to WDM
  - IP/WDM
- All optical networks
  - IP/ASON



# IP over Transport Networks: Evolution

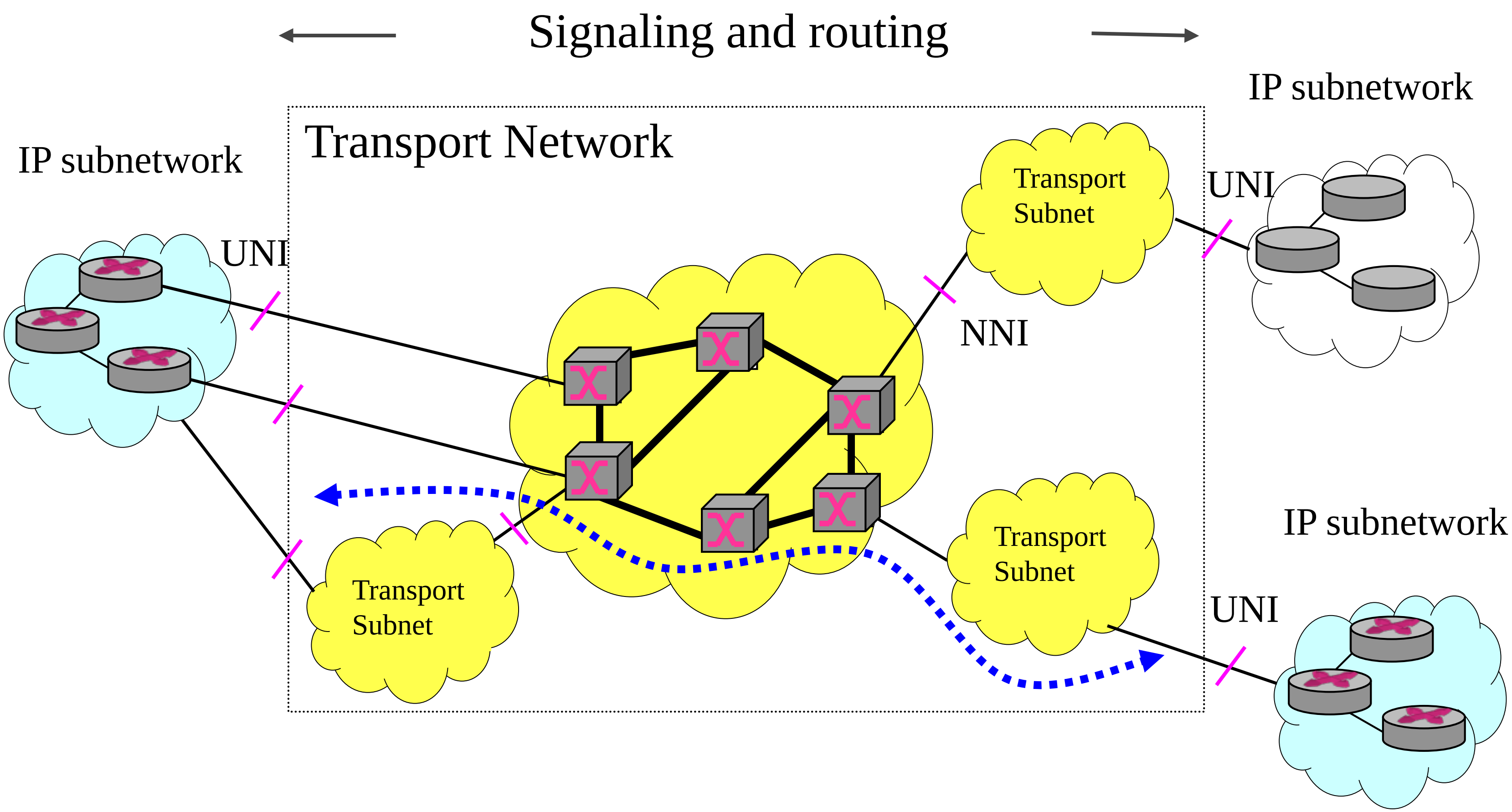
- Optical Internetworking




- Traffic Engineering → Control Plane
- Quality of Service (QoS)
- Protection and Restoration

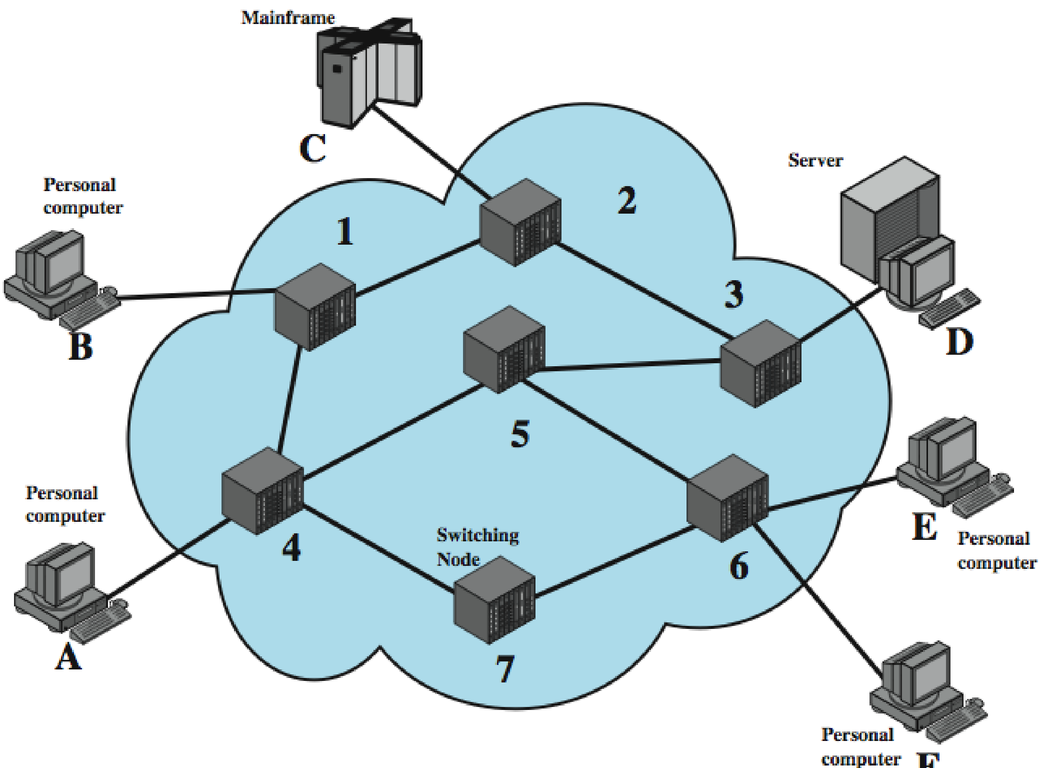
# Example of Network Configuration

- IP over a transport network



# Types of Backbone Networks

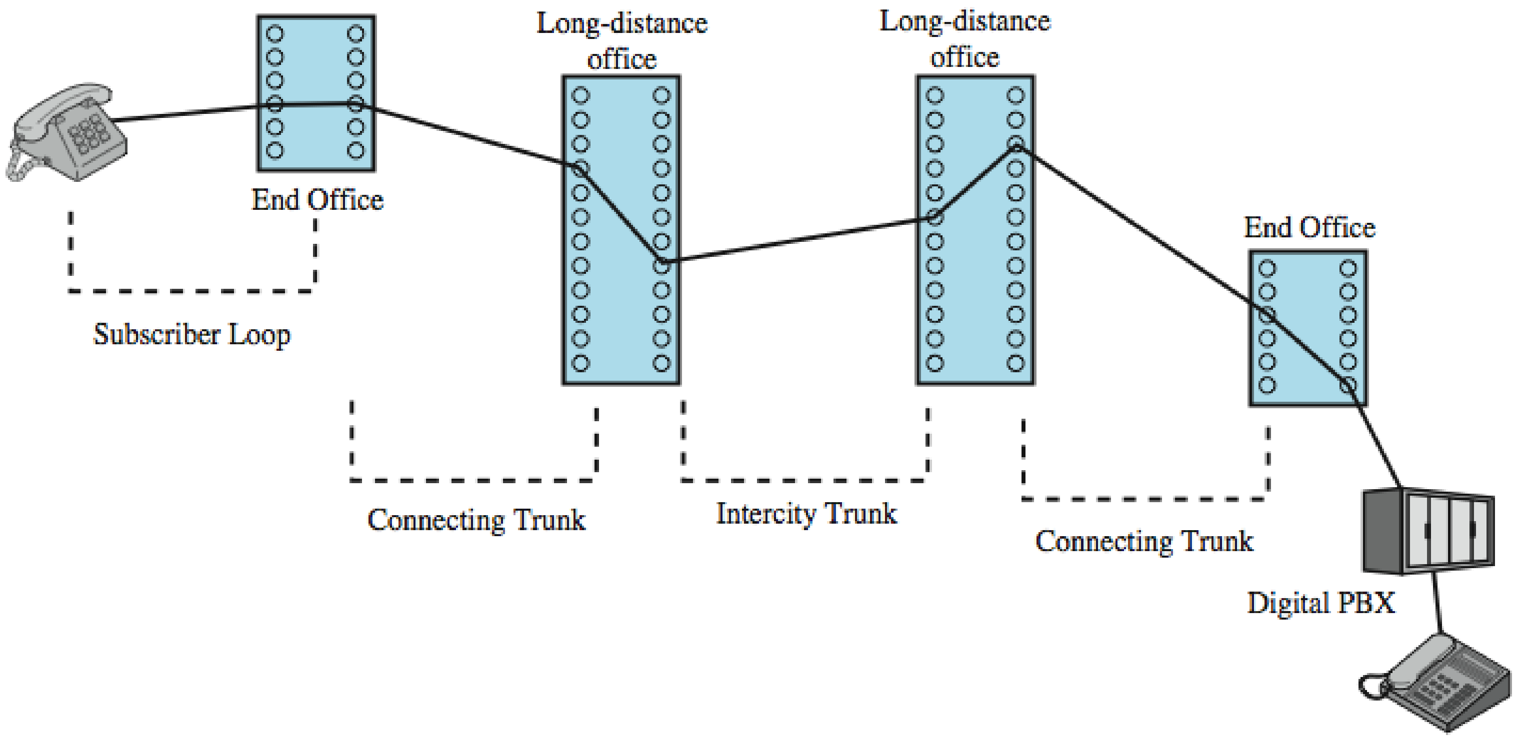
- Circuit Switched Networks
- Packet Switched Networks



# Circuit Switching

- Uses a **dedicated** path between two stations
- Has three phases
  - Establish
  - Transfer
  - Disconnect
- Inefficient for VBR traffic (data traffic)
  - Channel capacity dedicated for duration of connection
  - During idle periods, the capacity is wasted
- Set up (connection) takes time
- Once connected, transfer is transparent

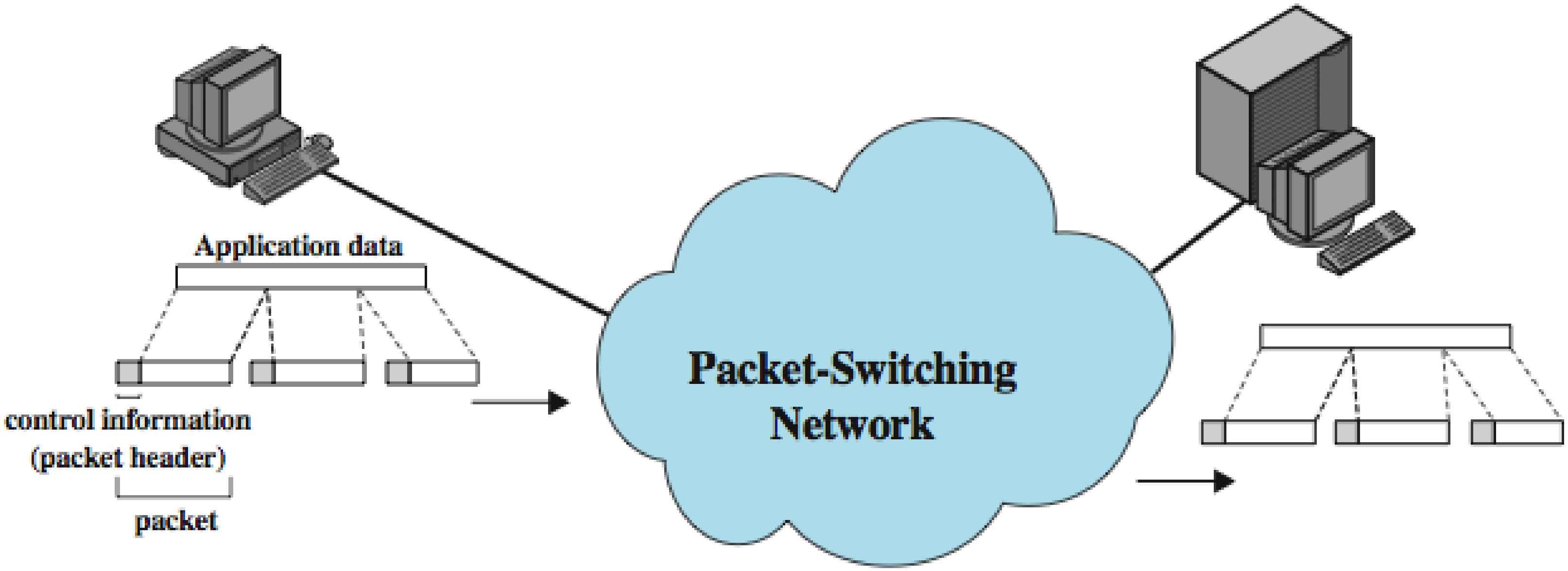
# Circuit Switched Network



# Packet Switching

- Station breaks long message into packets
- Packets sent one at a time to the network
- Packets can be handled in two ways
  - Datagram (Connectionless)
    - *E.g. IP network*
  - Virtual circuit (Connection Oriented)
    - *E.g. MPLS network*

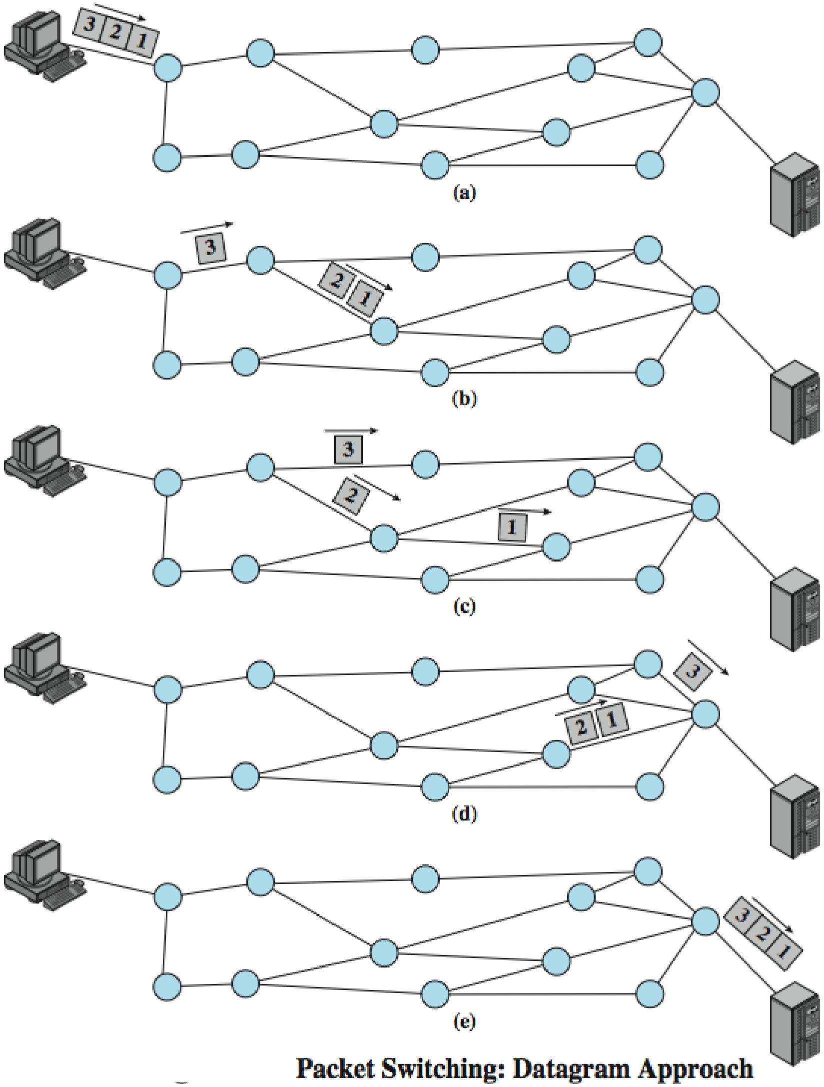
# Packet Switching Network



# Packet Switching advantages

- Line efficiency
  - Single link **shared** by many packets over time
  - Packets queued and transmitted as fast as possible
- Data rate conversion
  - Stations connects to local node at own speed
  - Nodes buffer data if required to equalize rates and resolve contentions
- Packets accepted even when network is busy
- Priorities can be used

# Datagram Diagram




Packet Switching: Datagram Approach

# Virtual Circuit Diagram

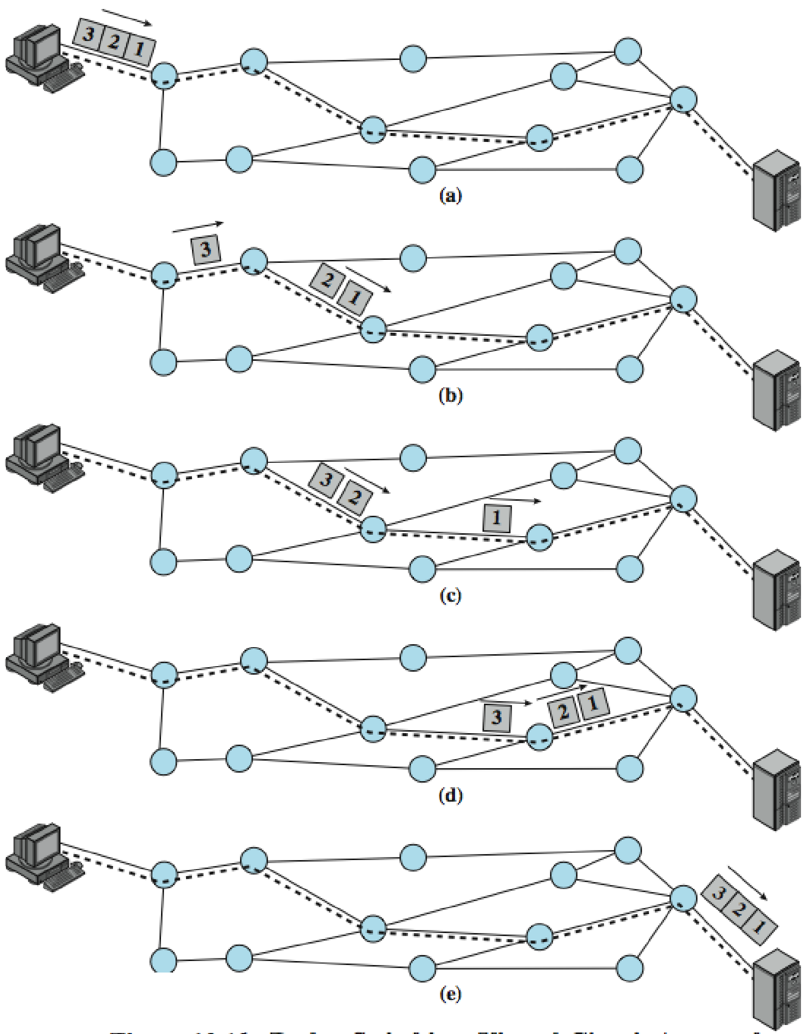
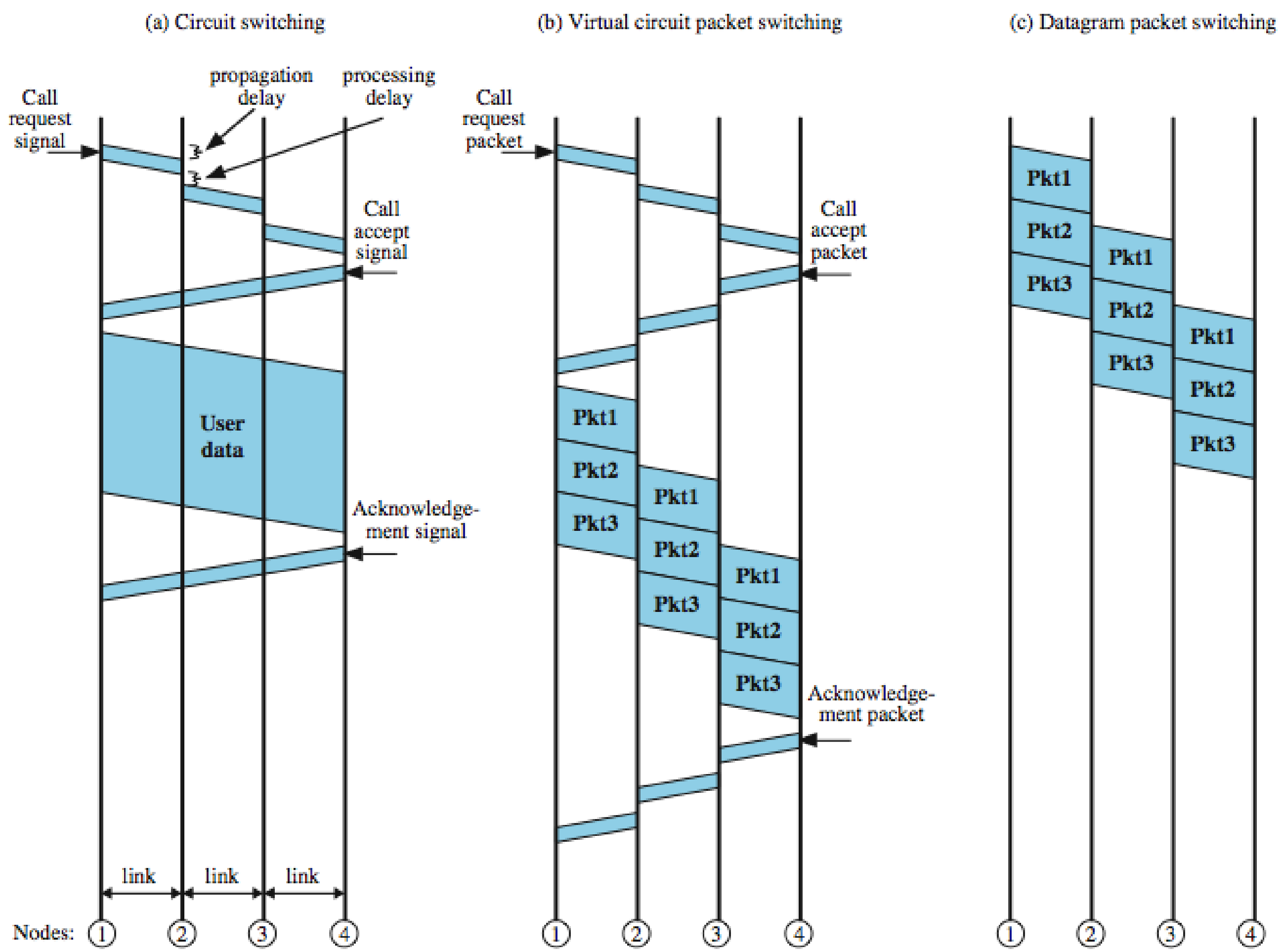



**Figure 10.10 Packet Switching: Virtual-Circuit Approach**

# *Virtual Circuits vs. Datagram*

- Datagram
  - No call setup phase
  - More flexible
  - More reliable
- Virtual circuits
  - Network can provide sequencing and error control
  - Packets are forwarded more quickly
  - Routing tables are less complex
  - Less reliable

# Event Timing



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# MultiProtocol Label Switching

The Internet Protocol Journal
Vol. 4, No. 3,
September 2001

William Stallings
Massachusetts Institute of Technology

# MPLS main features and capabilities

- Definition
  - MPLS is a successful effort to provide a network technology* to speed up the IP packet-forwarding process, and at the same time retain the flexibility of an IP-based networking approach
- MPLS main role
  - MPLS is a connection-oriented based scheme, which reduces the amount of per-packet processing required at each router in an IP-based network, enhancing router performance, and supports Quality of Service (QoS)

* Ascendant of Asynchronous Transfer Mode (ATM) networks

# The origins of MPLS (first draft in 1997)

| | |
|---|---|
| IBM | Aggregate Route-Based IP Switch (ARIS) |
| Cisco Systems | TAG switching |
| Nortel Networks | PORS |
| Toshiba | Cell Switched Router (CSR) |
| Nokia | Ipsilon IP Switching |
| Lucent Technologies Bell Labs Innovations | Ascend IP Navigator |
| The ATM Forum | MPOA |
| | . . . etc. |

IETF

MPLS

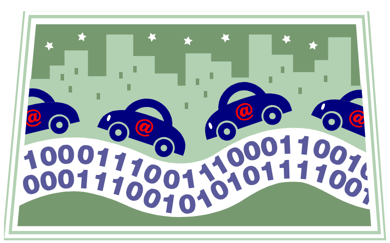
MPLS FORUM

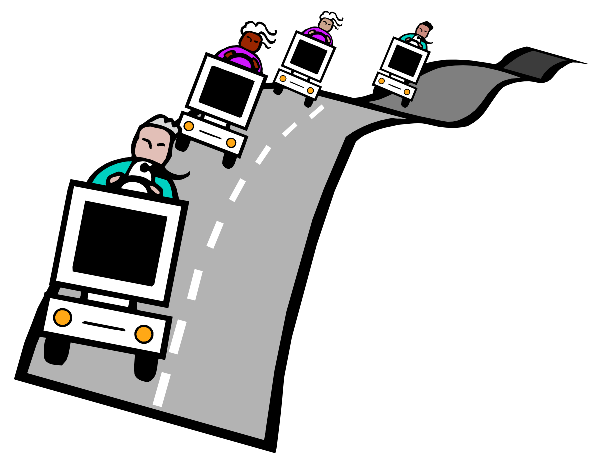
# Multiprotocol Label Switching (MPLS)

- MPLS is a set of IETF (Internet Engineering Task Force) specifications for including routing with **Traffic Engineering** information in packets
- Comprises a number of interrelated protocols
  - The MPLS protocol suite
- Is an efficient technique for forwarding and routing packets
- Is deployed by many telecommunication companies and service providers
- **Delivers the QoS required** to support real-time voice and video and SLAs that guarantee bandwidth

# Traffic Engineering

- IETF-RFC 2702:
  - Allocate traffic to the network to maximize utilization of the network capacity
  - Ensure the most desirable route through the network while meeting QoS requirements





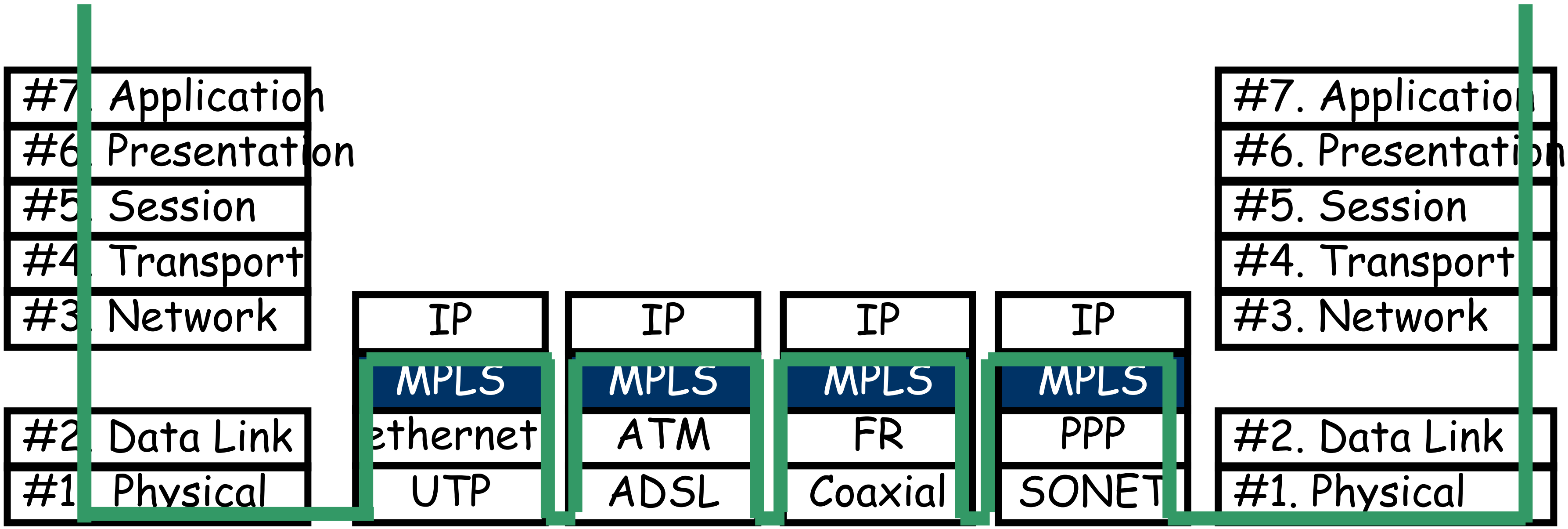
# Traffic Engineering

- Ability to define routes dynamically, plan resource commitments on the basis of known demand, and optimize network utilization
  - Paths can be routed and rerouted intelligently
- Effective use can substantially increase usable network capacity
- Other forms of traffic engineering
  - Basic IP networks just provides a primitive form of it, but
  - ATM provided strong traffic engineering capabilities prior to MPLS

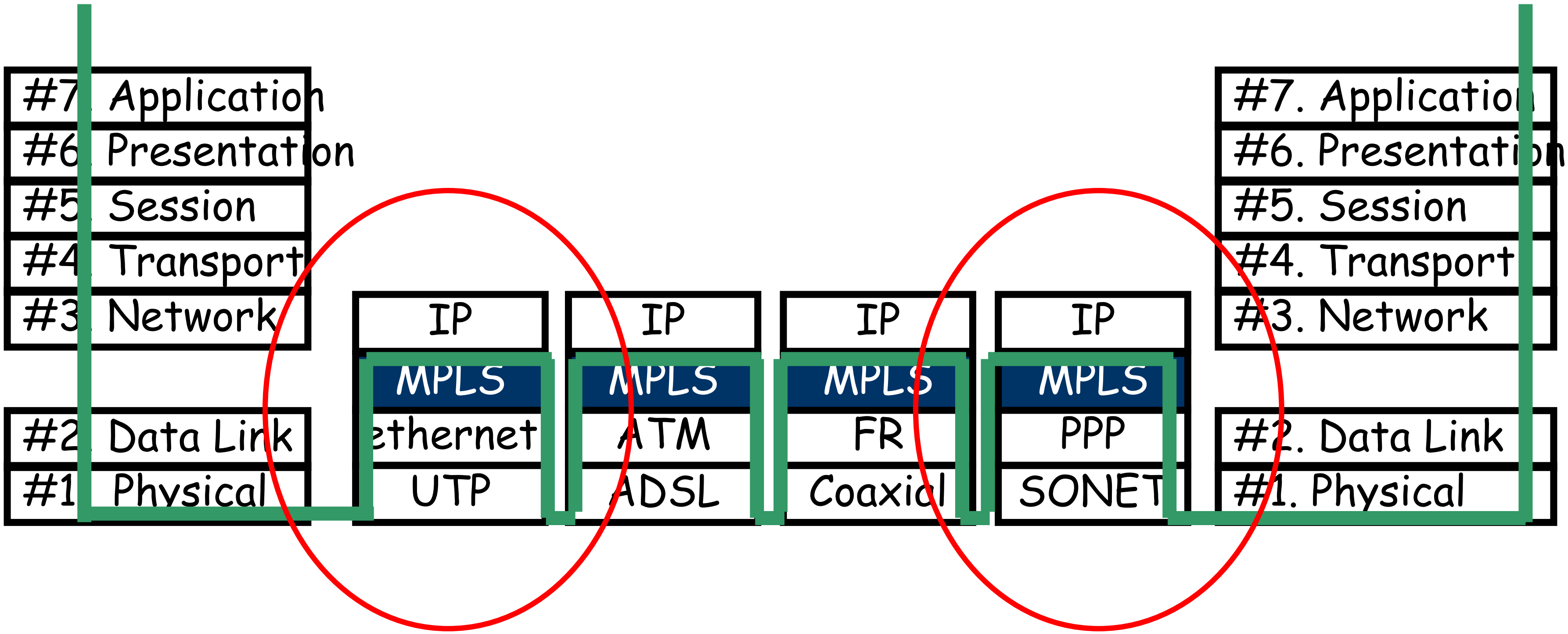
# Multiprotocol Label Switching (MPLS)

- Is designed with IP networks in mind
  - Can be used with **any link-level protocol**
- Is connection oriented
  - Which ensures that all packets in a particular flow take the same route over a backbone
- Uses a fixed-length label to encapsulate IP packets or data link frames (e. g. Ethernet)
  - MPLS label contains all information needed to perform routing, delivery, QoS, and traffic management functions

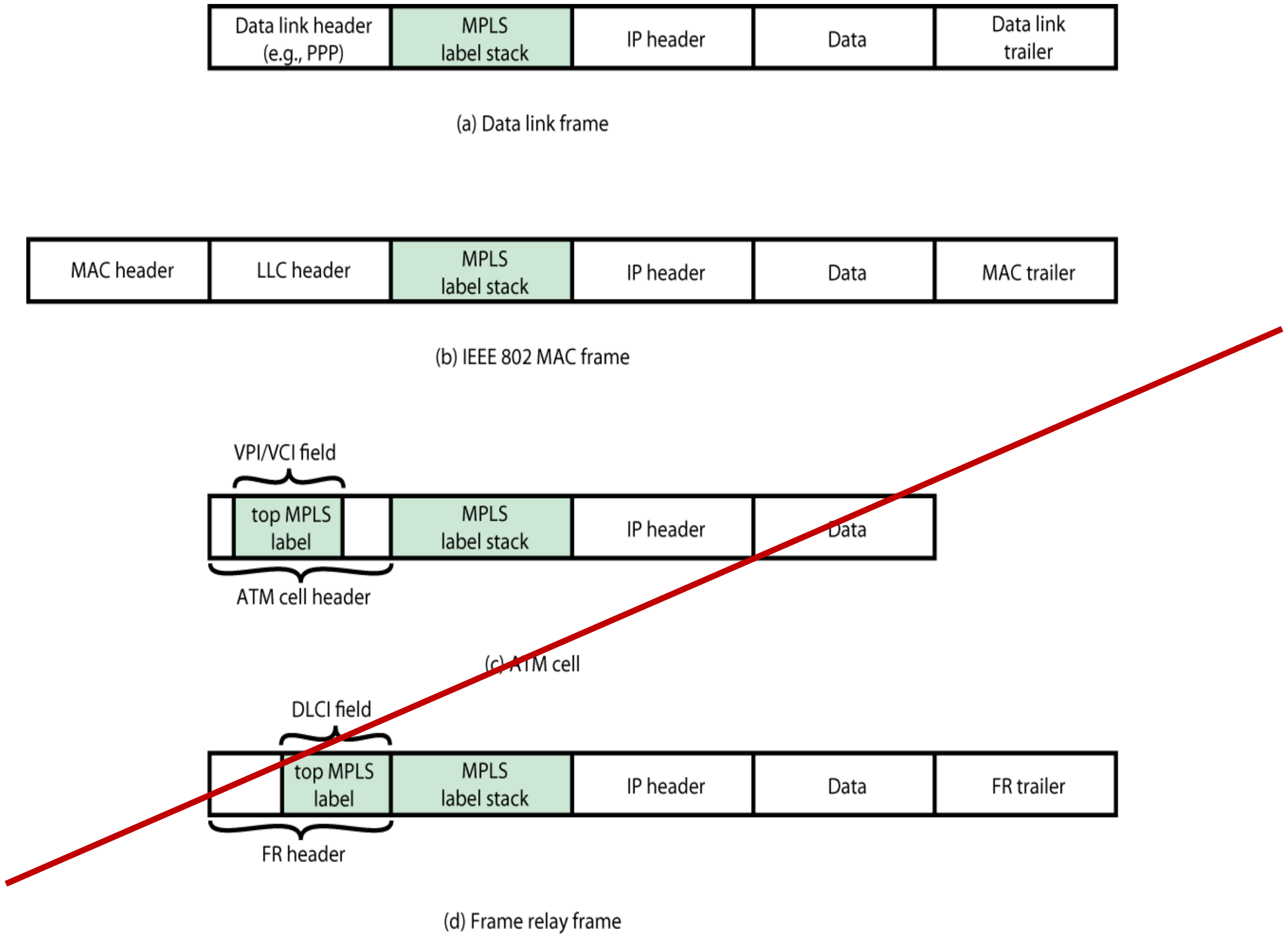
# MPLS position on the OSI Ref Model



# MPLS position on the OSI Ref Model



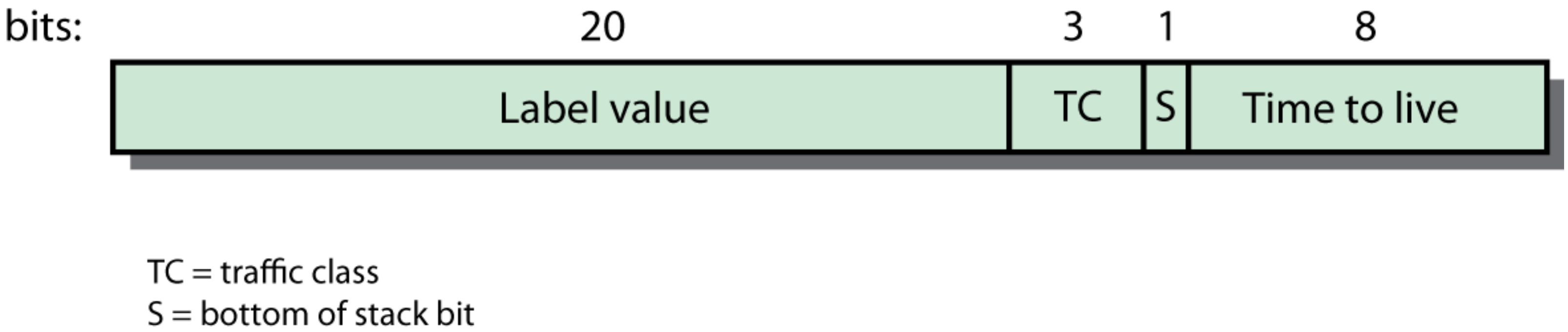
# MPLS position on the OSI Ref Model




Position of MPLS Label Stack

# MPLS Label Format

- IETF-RFC 3032:
- 32-bit field consisting of:
  - *Label value: 20 bits*
  - *Traffic class (TC): 3 bits*
  - *Bottom of Stack (S): 1 bit (S = 1 → last entry in label stack)*




MPLS Label Format

# IP Header vs MPLS Label

## IP Header

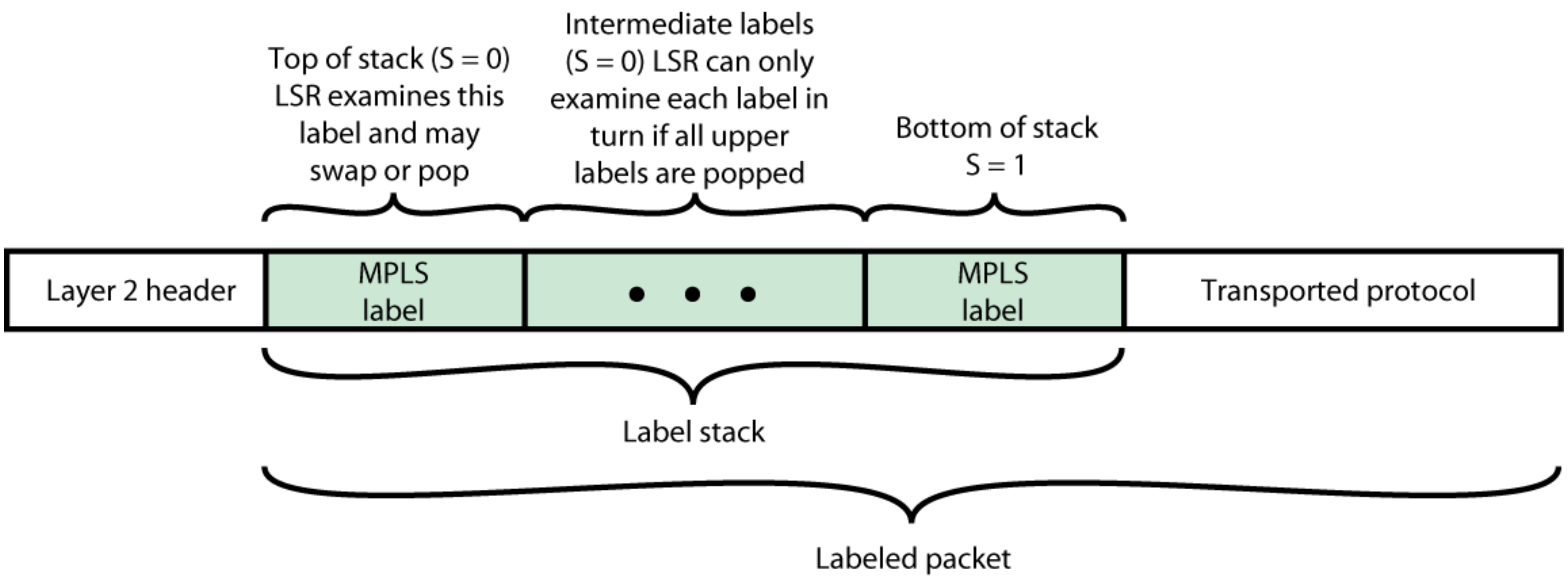
<table>
<tr><th colspan="2">0</th><th colspan="2">8</th><th colspan="3">16</th><th>31</th></tr>
<tr><td>VERS</td><td>HLEN</td><td colspan="2">Service Type</td><td colspan="4">Total Length</td></tr>
<tr><td colspan="4">Identification</td><td>Flags</td><td colspan="3">Fragment Offset</td></tr>
<tr><td colspan="2">TTL</td><td colspan="2">Protocol</td><td colspan="4">Header Checksum</td></tr>
<tr><td colspan="8">Source IP Address</td></tr>
<tr><td colspan="8">Destination IP Address</td></tr>
<tr><td colspan="6">Options</td><td colspan="2">Padding</td></tr>
</table>

## MPLS Label

<table>
<tr><th>0   8   16</th><th></th><th></th><th>31</th></tr>
<tr><td>Label</td><td>Exp</td><td>S</td><td>TTL</td></tr>
</table>

Label: Label value, 20 bits (0-16 reserved)
Exp.: Experimental, 3 bits (Class of Service)
S: Bottom of Stack, 1 bit (1 = last entry in label stack)
TTL: Time to Live, 8 bits

# Label Stacking




Encapsulation for Labeled Packet

# Label Stacking

- Label Stacking is one of the most powerful features of MPLS
  - At any LSR a label may be removed or added
  - Processing is always based on the top label
  - Unlimited stacking
- Label Stacking allows creation of tunnels
  - Tunnel refers to traffic routing being determined by labels
  - Provides considerable flexibility as well as the creation of VPNs

# Time to Live Field (TTL)

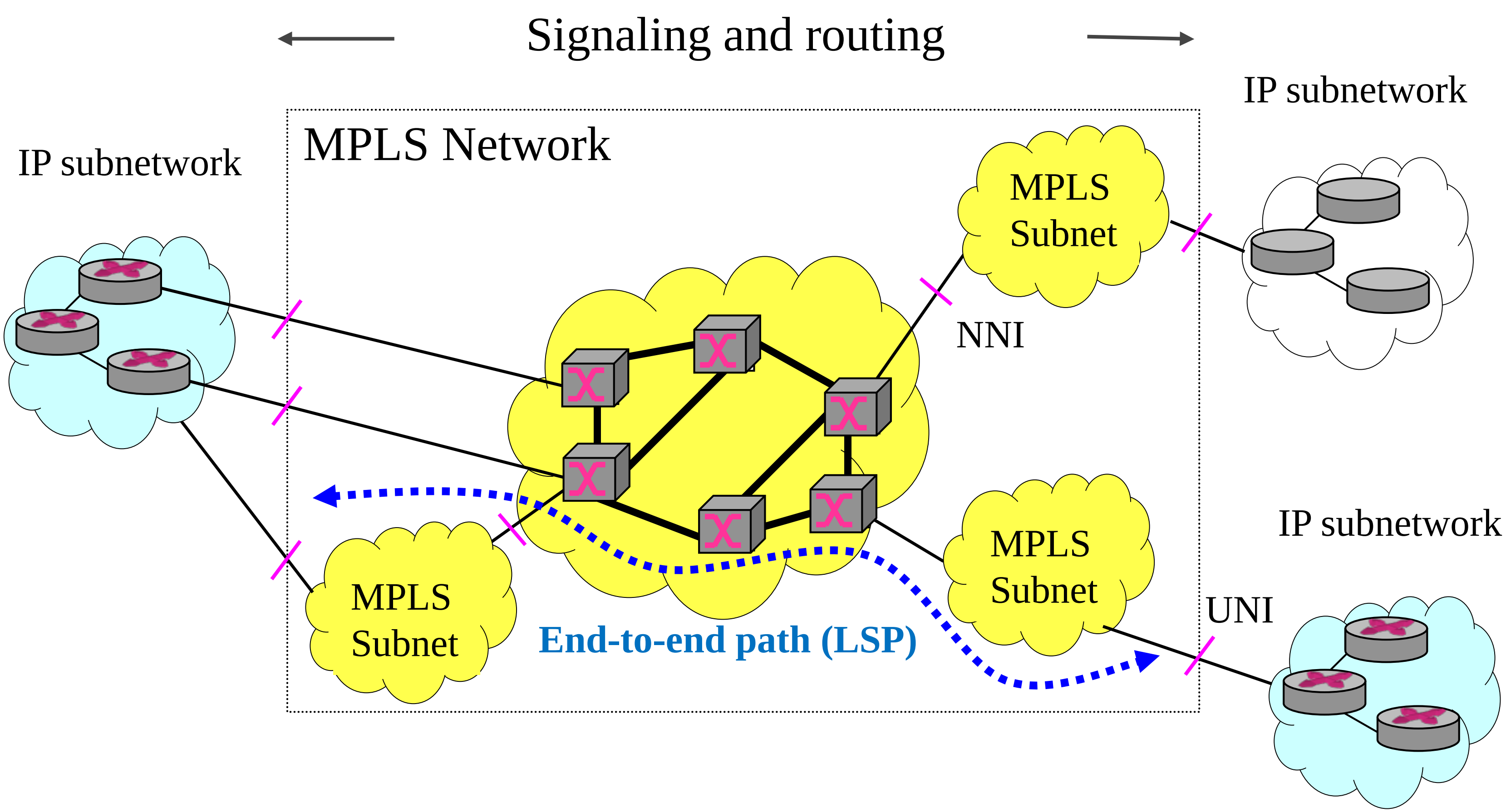
- Key field in the IP packet header
- Decremented at each router and packet is dropped if the count falls to zero
  - *Done to avoid looping. Avoids having the packet remain too long in the Internet due to faulty routing*
- Included in the label so that the TTL function is also supported by MPLS

# *In summary*

- MPLS provides significant new capabilities in four areas that have ensured its popularity:
  - Connection-oriented and QoS support,
  - Traffic engineering,
  - Virtual Private Networks (VPNs), and
  - Multiprotocol support

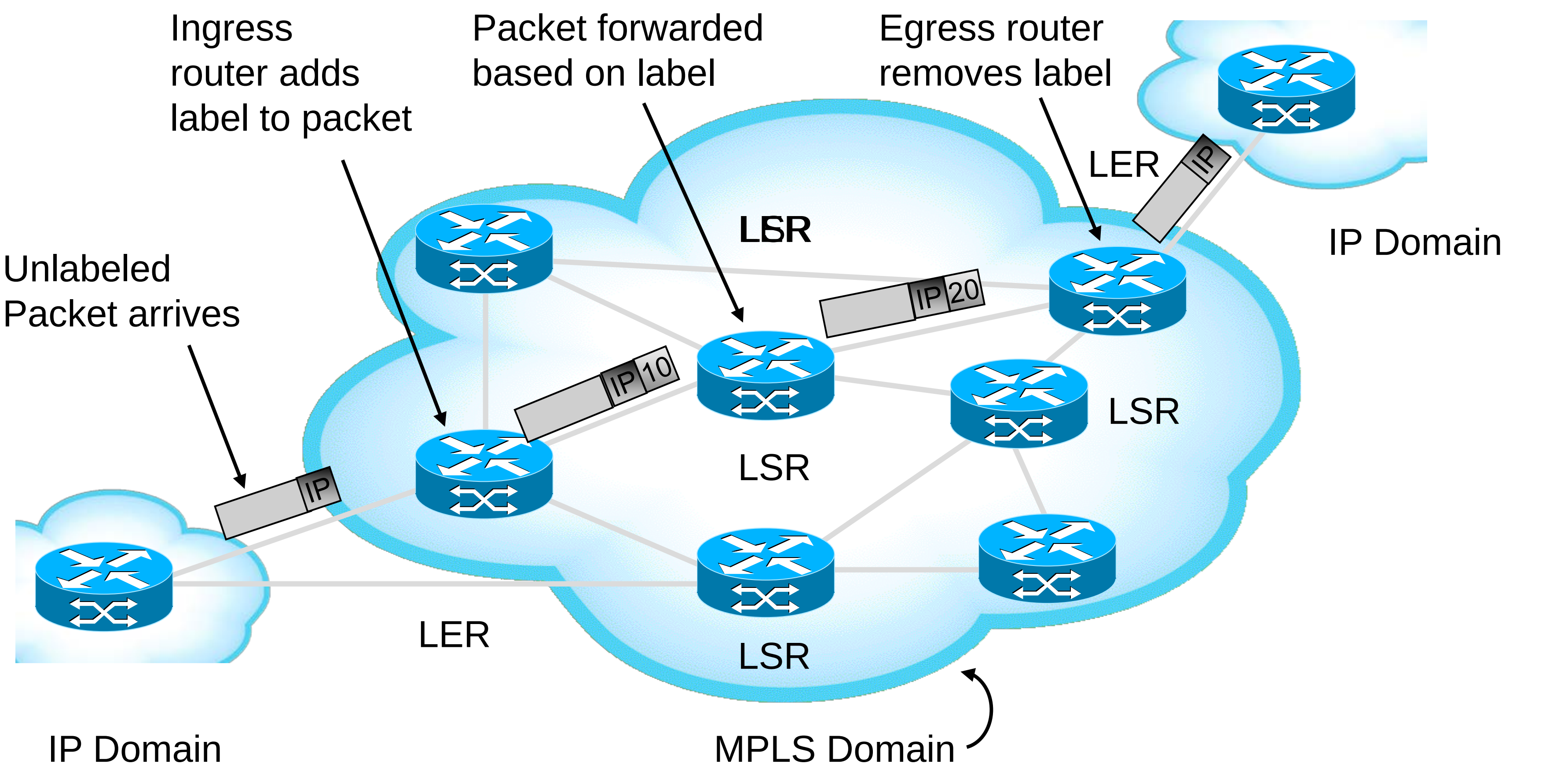
# MPLS in the core

- IP over MPLS network



# MPLS in the core

- How it works…

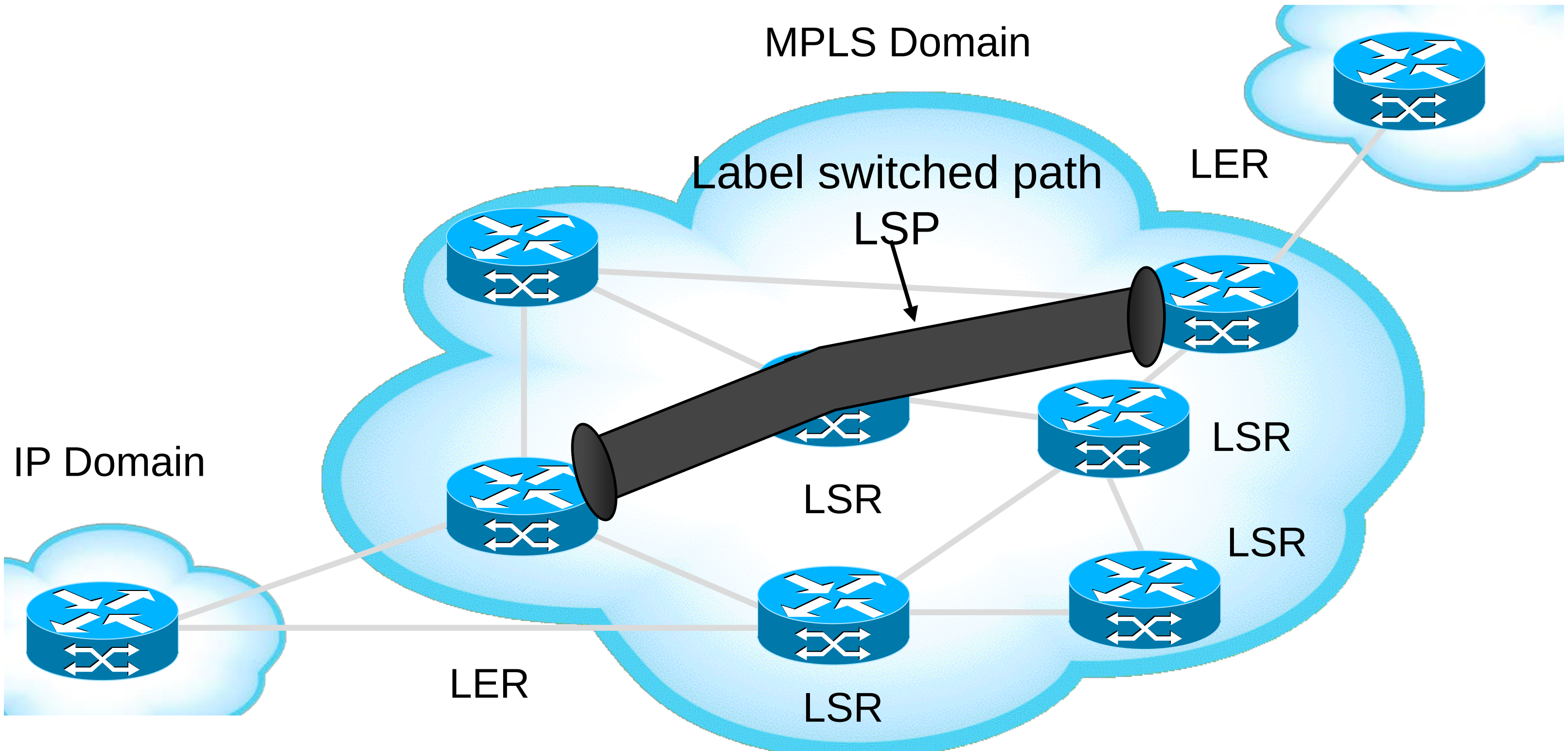


# Terminology

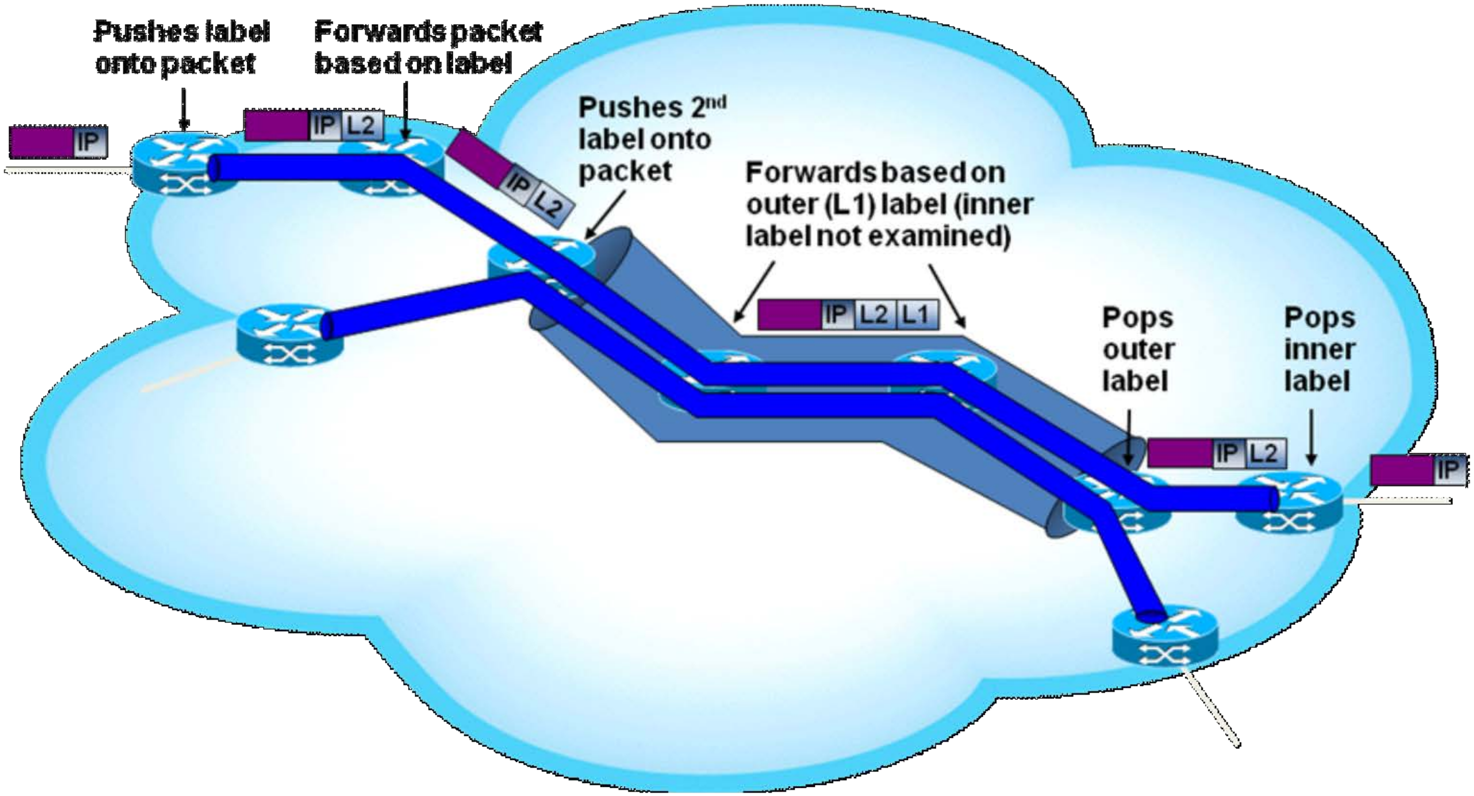
- LSP = Label Switched Path
- LSR = Label Switching Router
  - A router running MPLS software
- Some use:
  - LER = Router at start or end of LSP ("E" for "Edge")
  - LSR = Router in the middle of LSP

# MPLS in the core

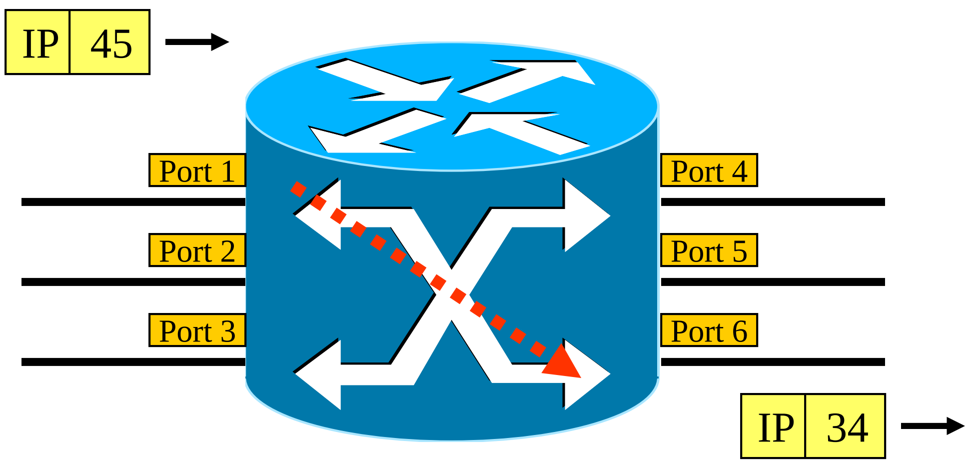
- Label Switched Path is like a pipe or tunnel
- While traveling on a label switched path, forwarding is based on the label only, not on destination IP address



# Example of Label Stacking



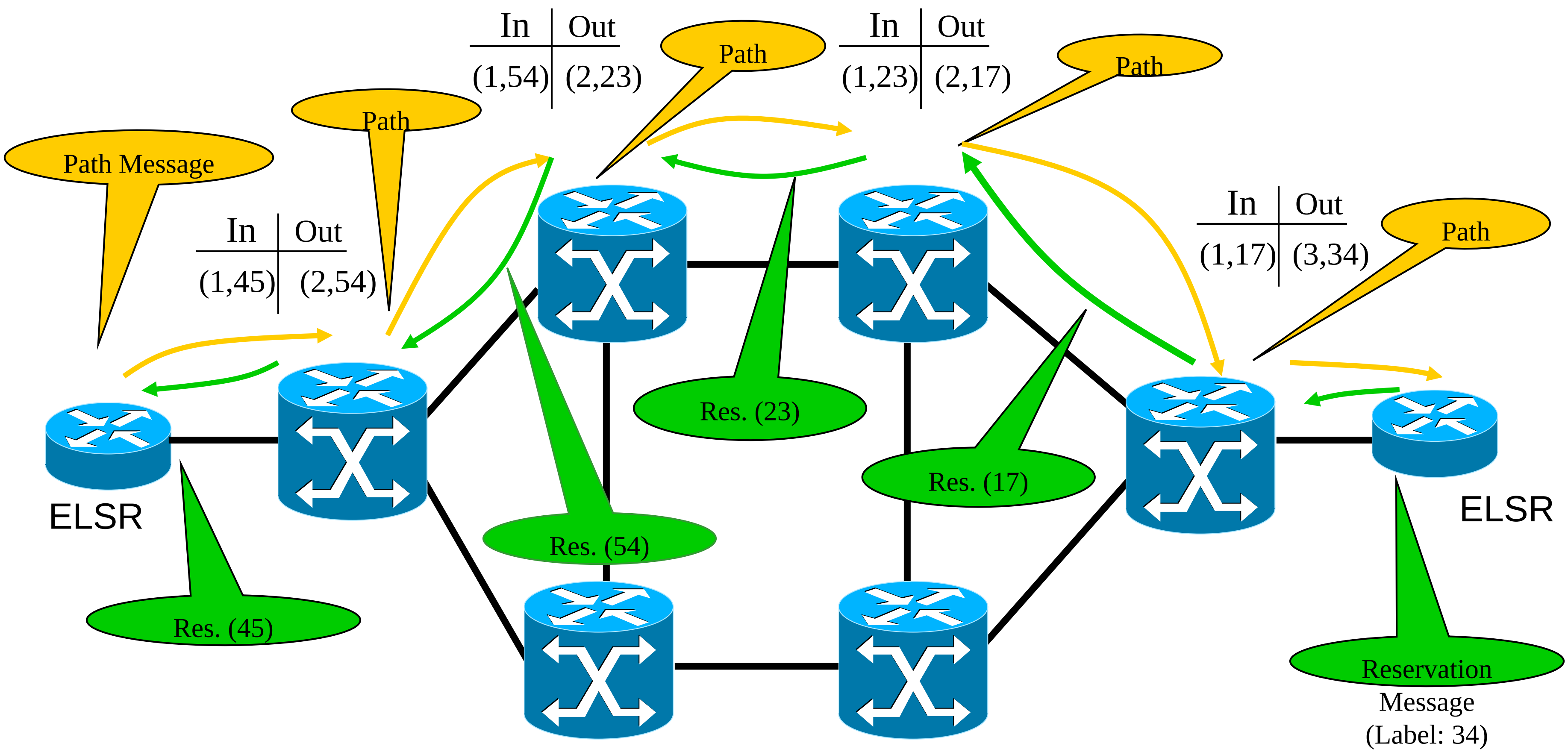
# Label Switching Router (LSR)




Forwarding Table

| In (port, label) | Out (port, label) | Operation Label |
|---|---|---|
| (1,35) | (4,56) | Swap |
| (1,45) | (6,34) | Swap |
| (2,12) | (4,13) | Swap |
| (3,24) | (5,24) | Swap |
| (3,37) | (6,49) | Swap |
| (3,19) | (6,19) | Swap |

# LSP Establishment: ReSerVation Protocol (RSVP-TE)



# Key MPLS Terms

**Forwarding equivalence class (FEC)** A group of IP packets that are forwarded in the same manner (e.g., over the same path, with the same forwarding treatment).

**Frame merge** Label merging, when it is applied to operation over frame based media, so that the potential problem of cell interleave is not an issue.

**Label merging** The replacement of multiple incoming labels for a particular FEC with a single outgoing label.

**Label swap** The basic forwarding operation consisting of looking up an incoming label to determine the outgoing label, encapsulation, port, and other data handling information.

**Label swapping** A forwarding paradigm allowing streamlined forwarding of data by using labels to identify classes of data packets that are treated indistinguishably when forwarding.

**Label switched hop** The hop between two MPLS nodes, on which forwarding is done using labels.

**Label switched path** The path through one or more LSRs at one level of the hierarchy followed by a packets in a particular FEC.

**Label switching router (LSR)** An MPLS node that is capable of forwarding native L3 packets.

**Label stack** An ordered set of labels.

**Merge point** A node at which label merging is done.

**MPLS domain** A contiguous set of nodes that operate MPLS routing and forwarding and that are also in one Routing or Administrative Domain

**MPLS edge node** An MPLS node that connects an MPLS domain with a node that is outside of the domain, either because it does not run MPLS, and/or because it is in a different domain. Note that if an LSR has a neighboring host that is not running MPLS, then that LSR is an MPLS edge node.

**MPLS egress node** An MPLS edge node in its role in handling traffic as it leaves an MPLS domain.

**MPLS ingress node** An MPLS edge node in its role in handling traffic as it enters an MPLS domain.

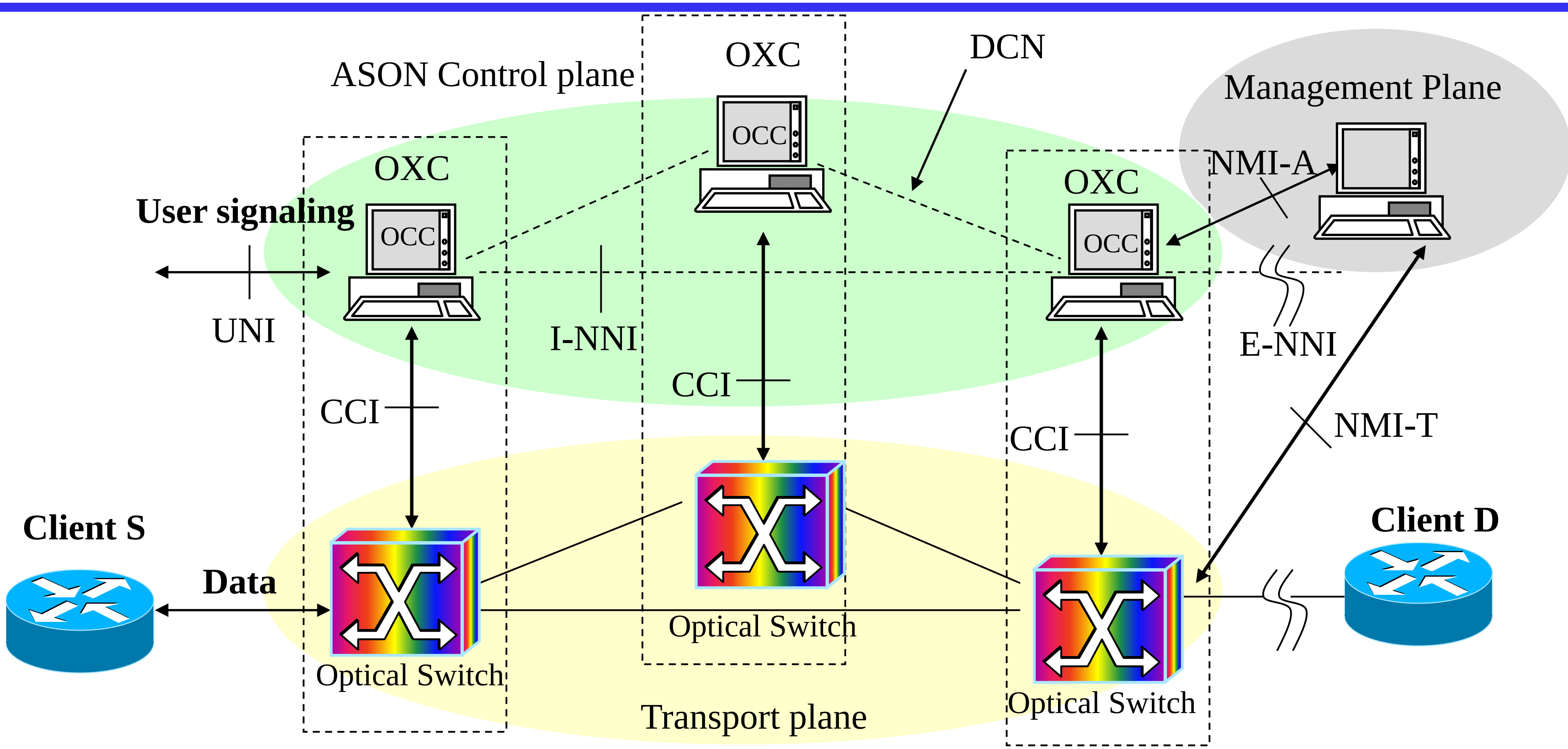
**MPLS label** A short, fixed-length physically contiguous identifier that is used to identify a FEC, usually of local significance. A label is carried in a packet header.

**MPLS node** A node that is running MPLS. An MPLS node will be aware of MPLS control protocols, will operate one or more L3 routing protocols, and will be capable of forwarding packets based on labels. An MPLS node may optionally be also capable of forwarding native L3 packets.

# *GMPLS based Control Plane*

Courtesy of Raül Muñoz (CTTC)

# ASON logic architecture




CCI: Connection Control Interface

NMI-A: Network Management Interface for ASON Control Plane

NMI-T: Network Management Interface for the Transport Network

DCN: Data Communication Network

OCC: Optical Connection Controller

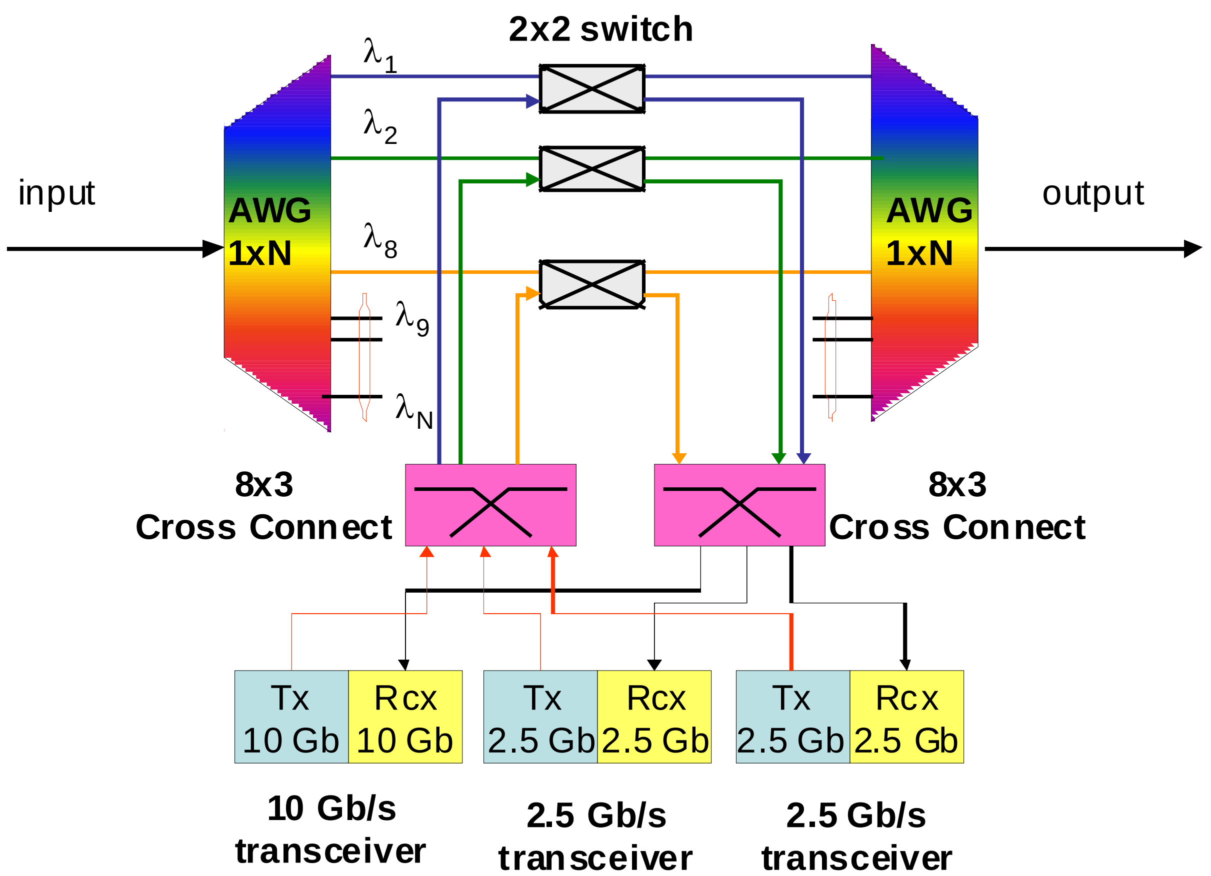
UNI: User to Network Interface.

NNI: Network to Network Interface

OXC: Optical Cross Connect.

# Optical Switch architecture: Example 1

- R-OADM: Reconfigurable Add and Drop Multiplexer

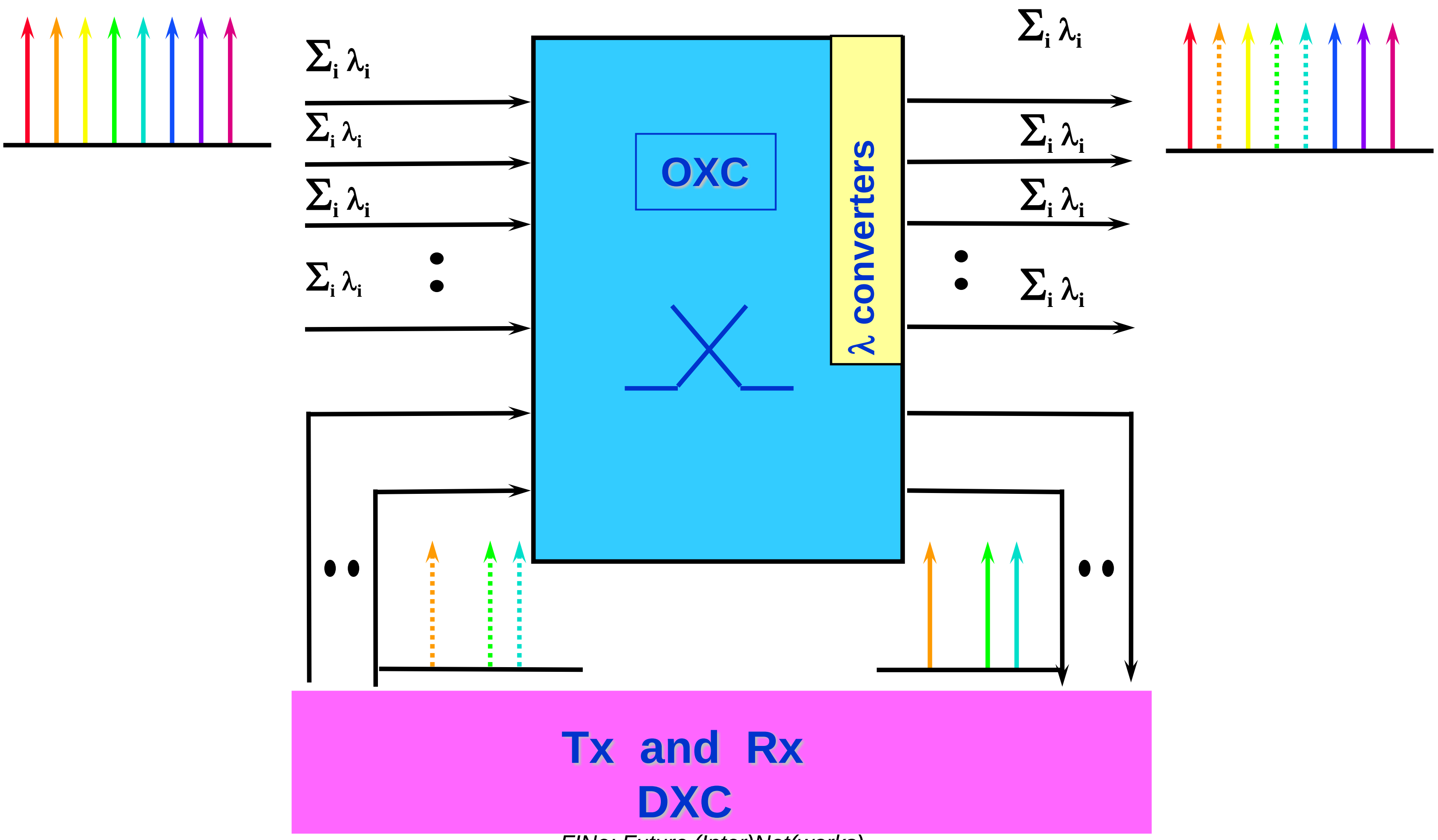


# Wavelength Division Multiplexing (WDM)

- **An analogy**

# Optical Switch architecture: Example 2

- OXC - OADM



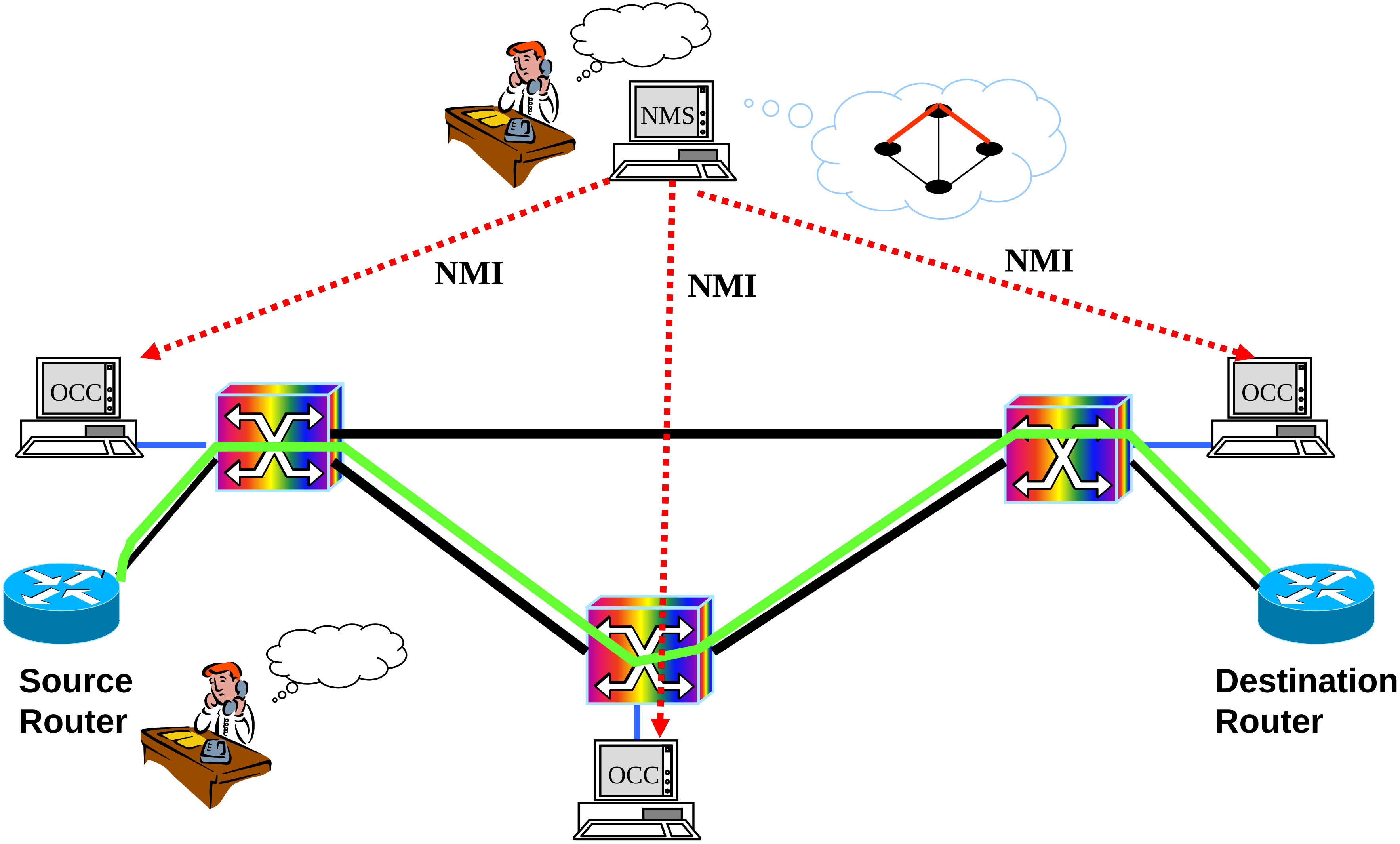
# ASON logic architecture

- Transport Plane:
  - It consists of an optical transport network that provides unidirectional or bi-directional optical channels between end-users, and detects status information of the connection (e.g., breakdowns, signal quality, etc.), and inform about it to the other two planes
- Control Plane:
  - Supports the set up and tear down of connections as a result of a requests triggered from the clients on the network (dialup connection) or a request from the NMS management system (soft-permanent connections)
- Management Plane:
  - Performs management functions (fault, configuration, accounting and security) for transport planes and control

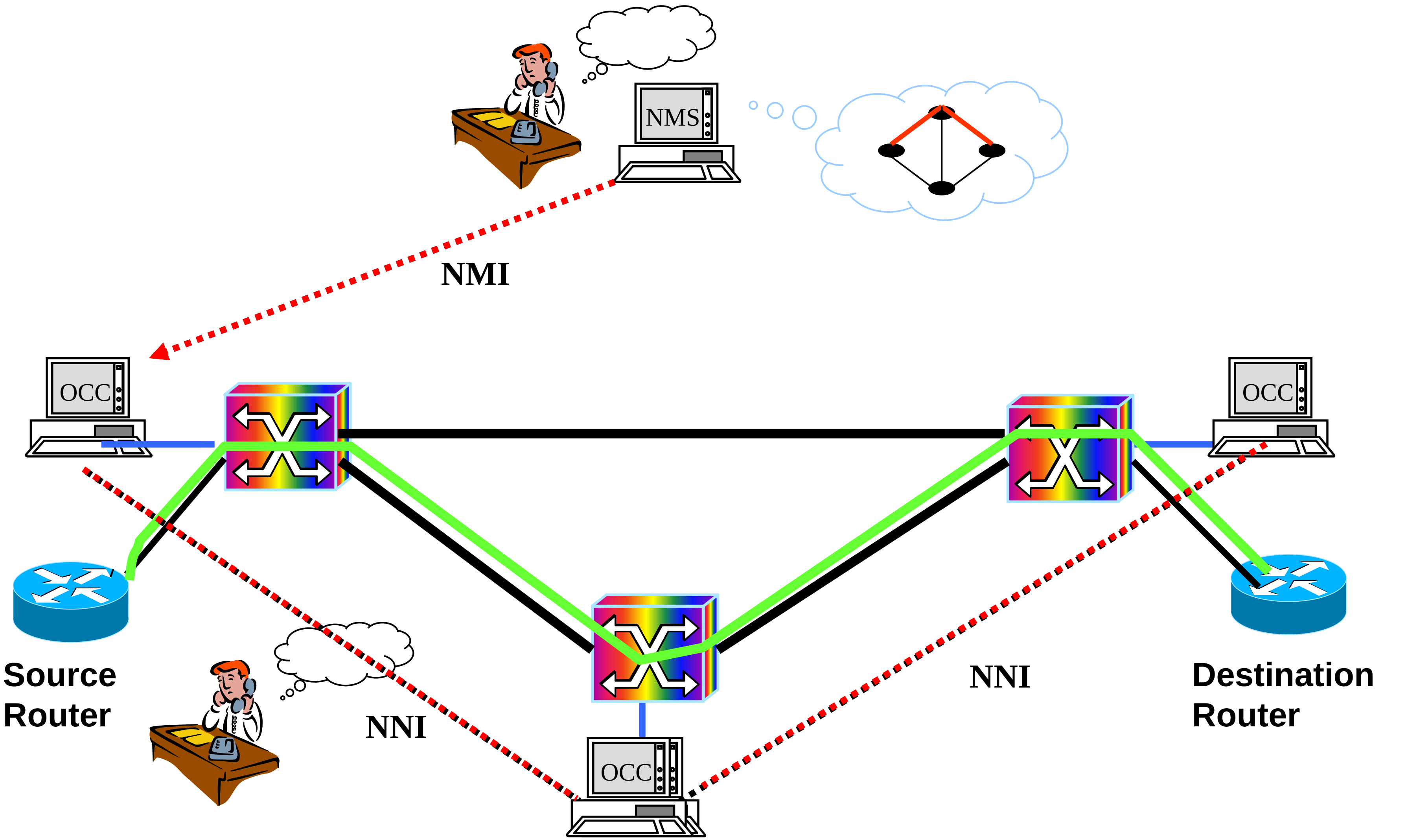
# Optical Transport Services

- Permanent OCh:
  - Established from the network management system through the network management protocols (NMI)
- Soft Permanent OCh:
  - Established from the network management system, but through network signaling and routing protocols (NNI and NMI)
- Switched OCh:
  - Established on demand directly by the client through network signaling and routing protocols (UNI and NNI)

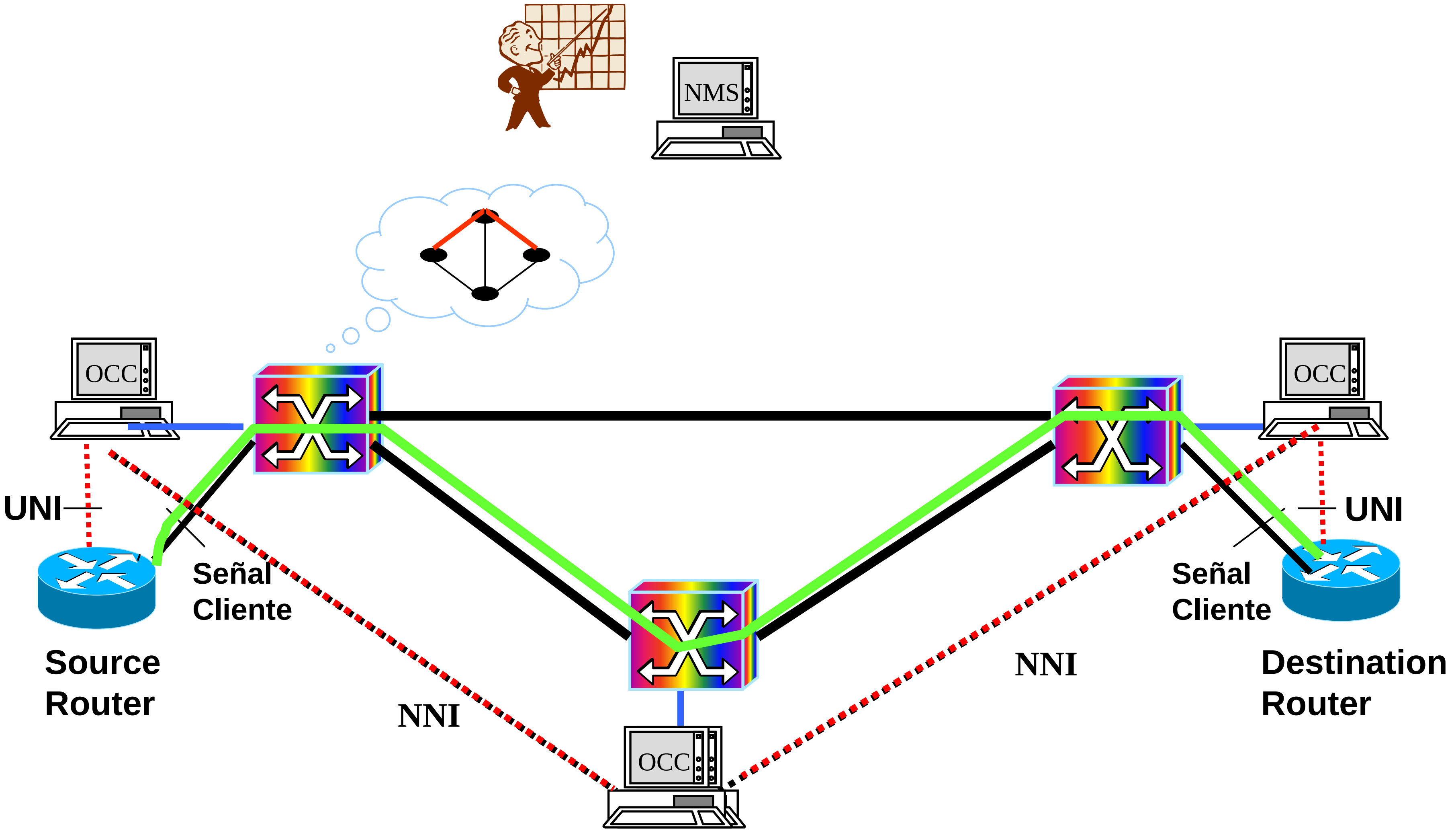
# Permanent Optical Channels



# Soft-Permanent Optical Channels



# Switched Optical Channels



# Control Plane requirements

- The control plane consists of the following key components:
  - An addressing scheme
  - A signaling network connecting all the OCC
  - A signaling protocol to set up/ tear down optical channels
  - Routing / Neighbor discovery Protocols

# The GMPLS based Control Plane

- Key direction: Not reinventing the wheel

decisions taken ⬇

- Adapting the Control Plane of the MPLS networks to the Optical networks
- Such and extension is possible thanks to the huge similarities between the OXC and the LSR
- And is known as:
  - *MP$\lambda$S Control Plane, for the specific case of WDM networks*
  - *GMPLS Control Plane for the general case*
- The Routing and Signaling Protocols, and the Addressing scheme are IP based

# The GMPLS Protocols set

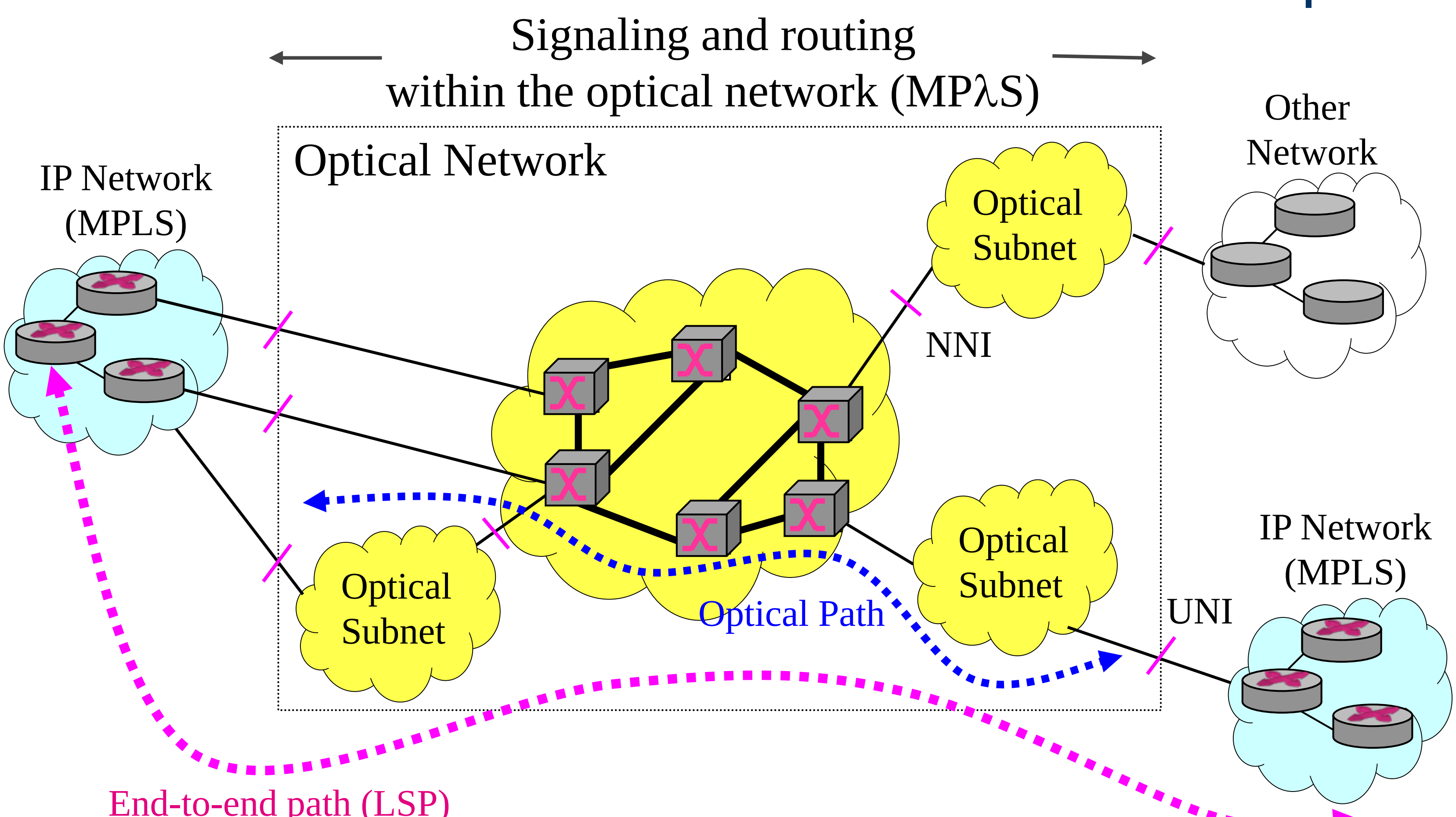
- Dynamic (Automatic) Neighbor Discovery:
  - Link Management Protocol (LMP) with extensions
- Discovery / Dissemination of the topology and of the available resources dynamically using
  - Link-state Routing Protocols
    - *OSPF with TE extensions*
    - *BGP-4 with optical inter-domain extensions*
- Signaling for dynamically (in real time) set up / reroute / tear down optical channels
  - Reuse of the RSVP-TE protocol with extensions

# MPLS extensions to build up the MPλS Control Plane

- MPλS is a subset of the GMPLS
- The MPλS Control Plane extensions were done according the following criteria:
  - Using the wavelengths as labels
  - Considering the optical channels as LSPs
- There is a clear relationship between the tuples <*input port, input label*> and <*input port, input lambda*>*,* and <*output port, output label*> *and* <*output port, output lambda*>
- When only a single signaling channel is available (used) to control multiple optical channels, the label, besides of the value of the wavelength, may contain an optical link identifier (*Link ID*)

# IP over OTN/ASON Scenario

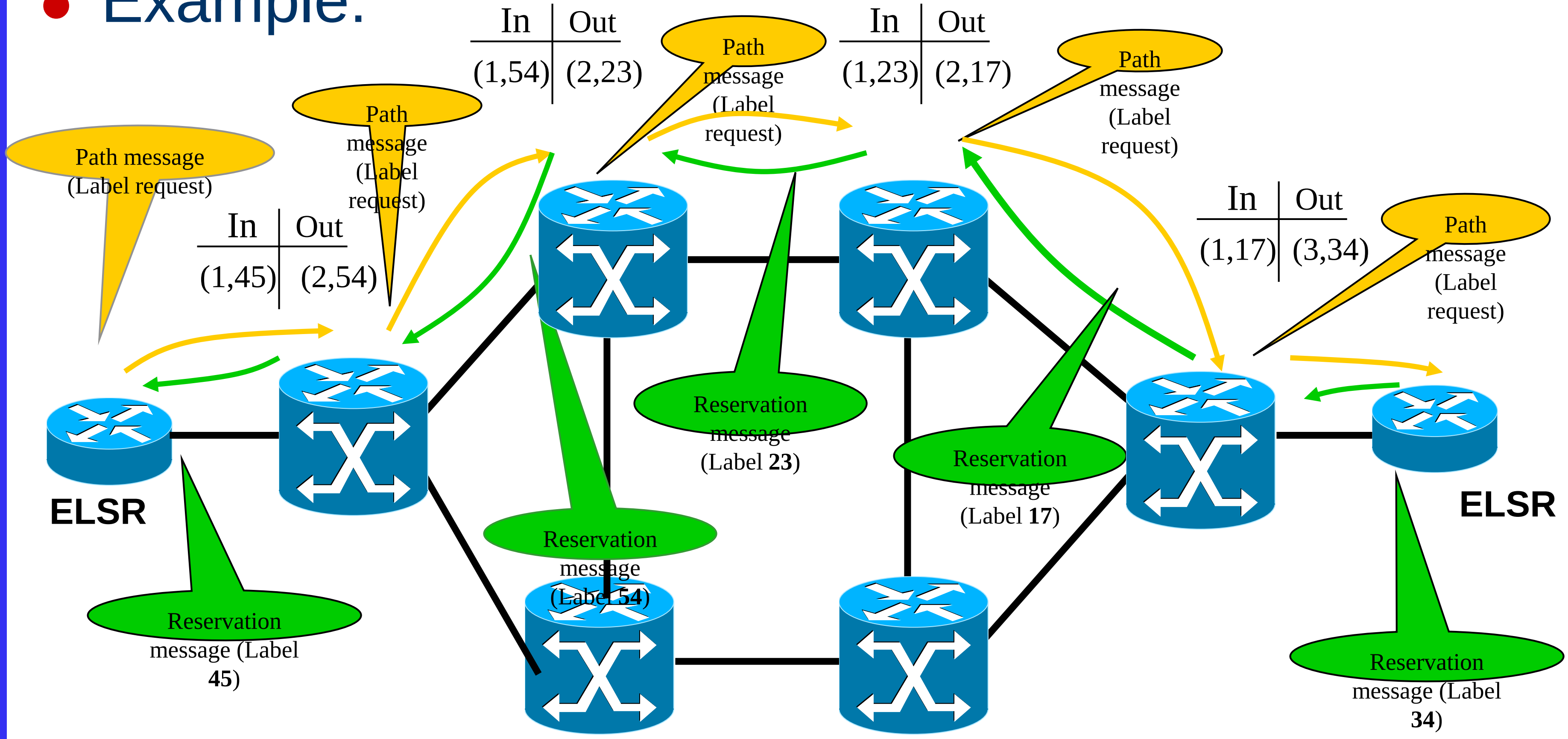
- MPLS and GMPLS Control Planes interoperability




Ref.: OIF, Bala Rajagopalan

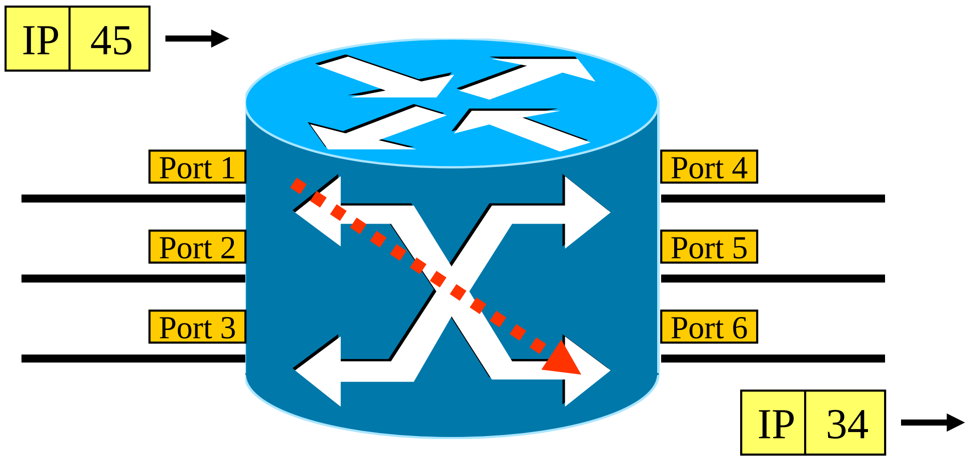
# LSP set up

- Example:



# Label Switching Routers (LSR)

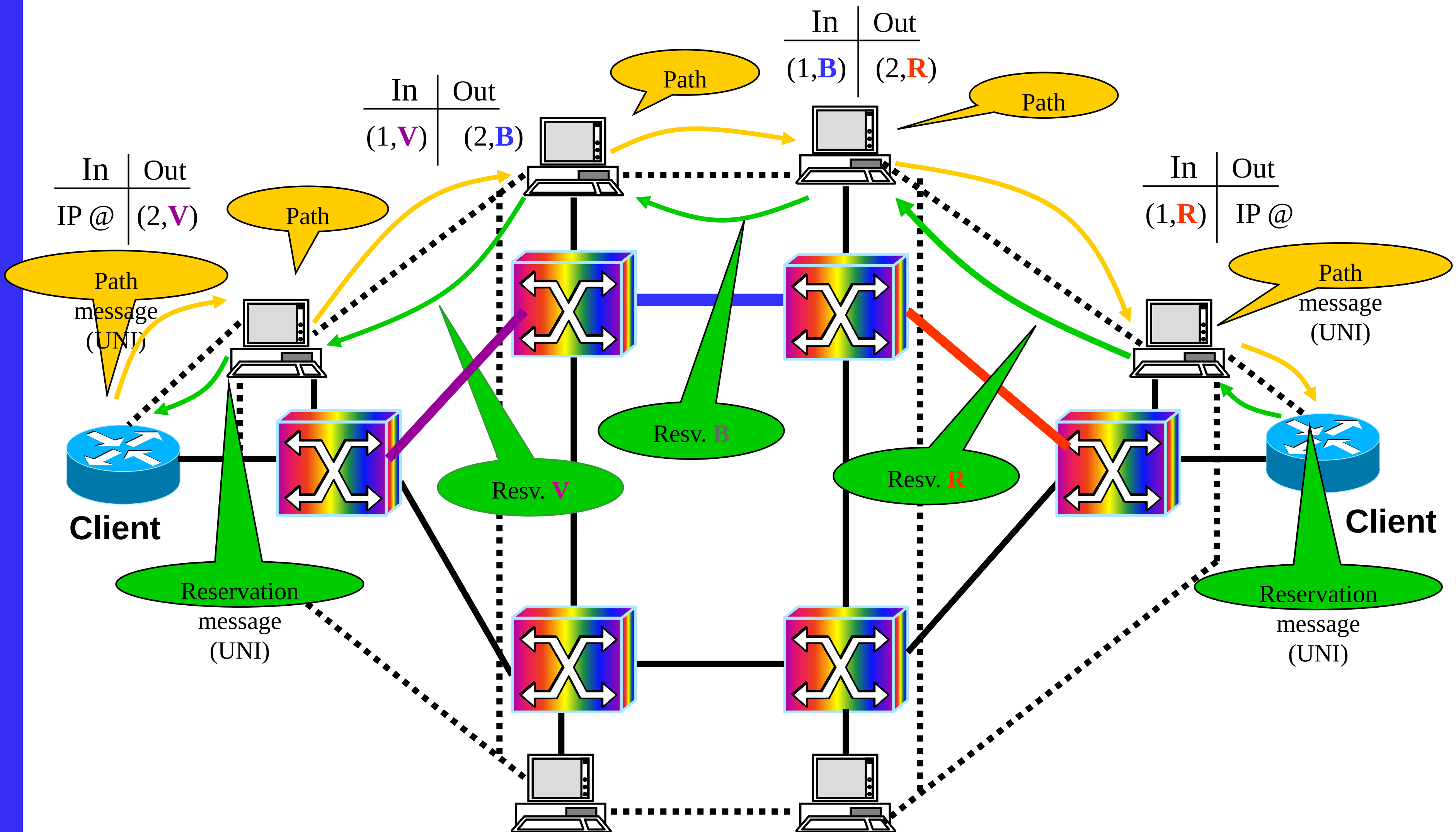
- MPLS LSRs perform label switching establishing a relationship between the pair <*input port, input label*> and the pair <*output port, output label*>
- Example:




**Forwarding table**

| Input | Output | Function |
|---|---|---|
| (port, label) | (port, label) | Label |
| **(1,35)** | **(4,56)** | **Swap** |
| **(1,45)** | **(6,34)** | **Swap** |
| **(2,12)** | **(4,13)** | **Swap** |
| **(3,24)** | **(5,24)** | **Swap** |
| **(3,37)** | **(6,49)** | **Swap** |
| **(3,19)** | **(6,19)** | **Swap** |

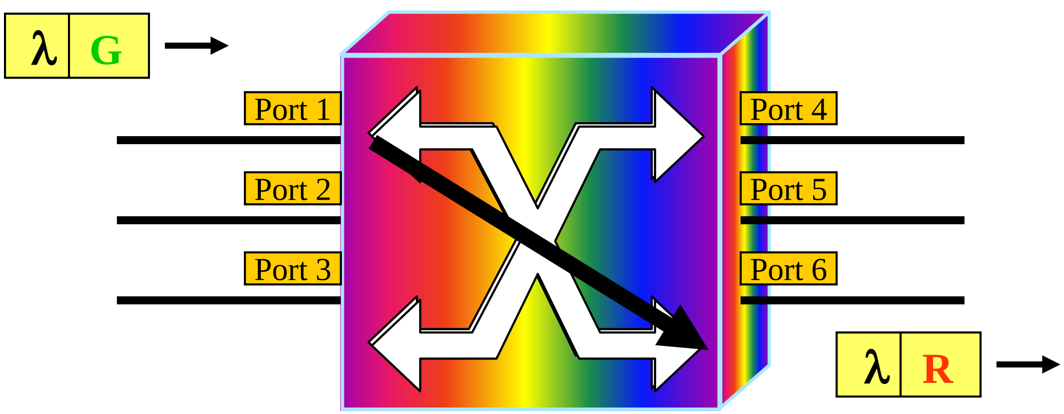
# Optical Path set up



# Optical Cross Connects (OXC)

- OXCs provide optical paths establishing relationships between <*input port, input wavelength*> and <*output port, output wavelength*>

- Example:



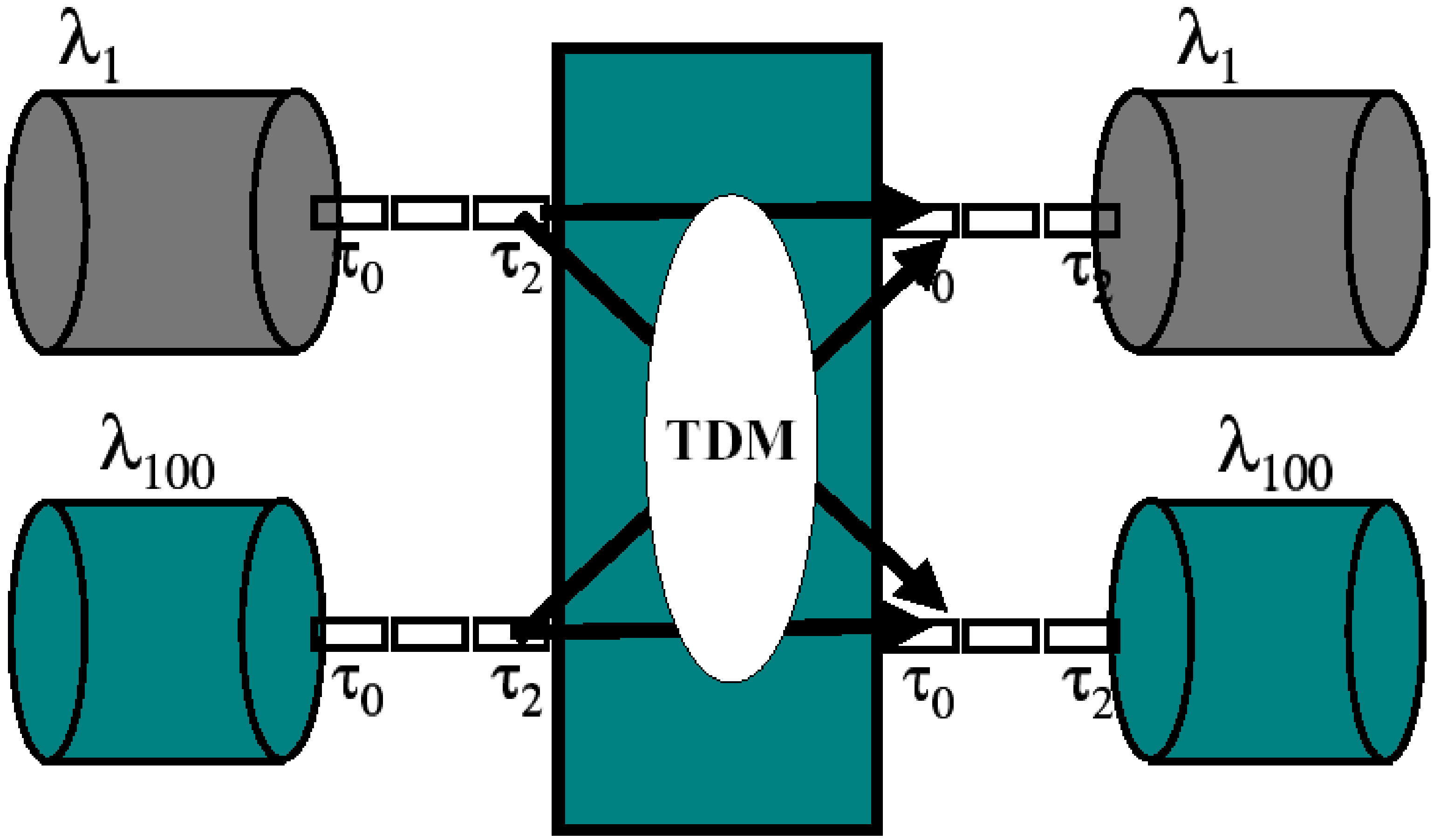

**Forwarding table**

| Input (port, label) | Output (port, label) | Fuction Label… |
|---|---|---|
| **(1,B)** | **(4,G)** | **Swap** |
| **(1,G)** | **(6,R)** | **Swap** |
| **(2,R)** | **(4,Y)** | **Swap** |
| **(3,Y)** | **(5,R)** | **Swap** |
| **(3,G)** | **(6,G)** | **Swap** |
| **(3,B)** | **(6,Y)** | **Swap** |

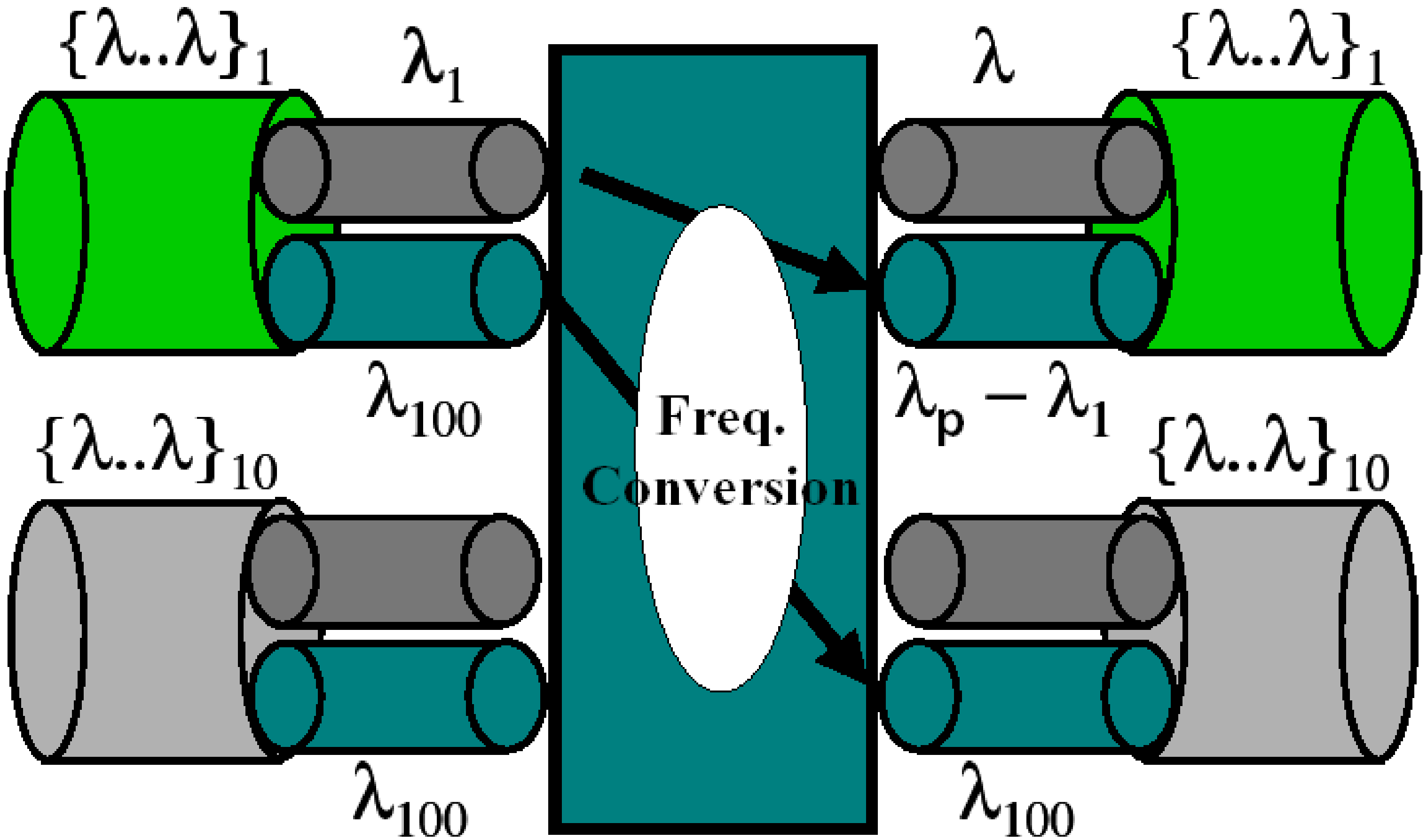
# MPLS Switching Classes

- MPLS – MultiProtocol Label Switching
  - The basic packet switching mode
- MP$\lambda$S – MultiProtocol Lambda Switching
  - MPLS for controlling Optical Paths
- GMPLS – Generalized MPLS
  - MPLS for controlling any type of channels (including SDH circuits)

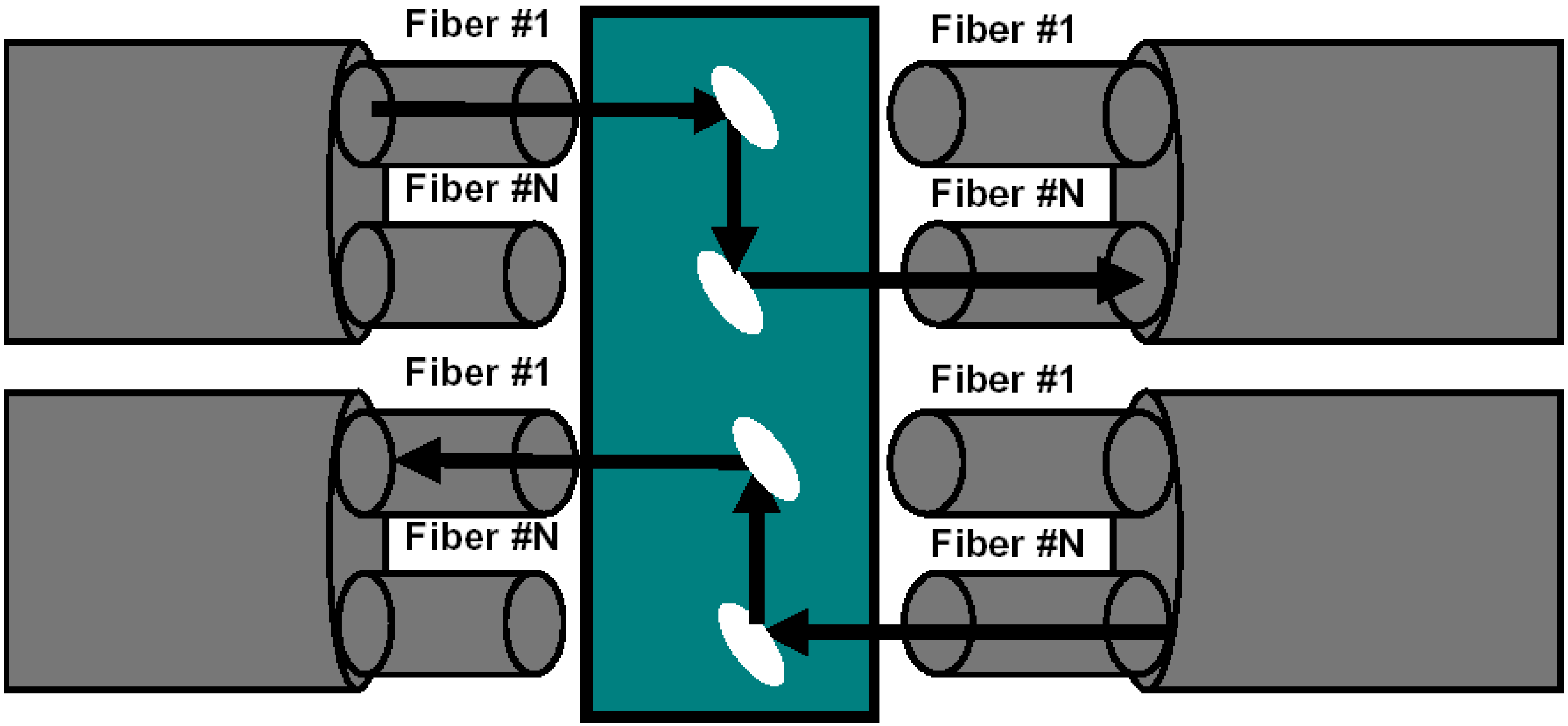
# TDM (SONET/SDH) Switching



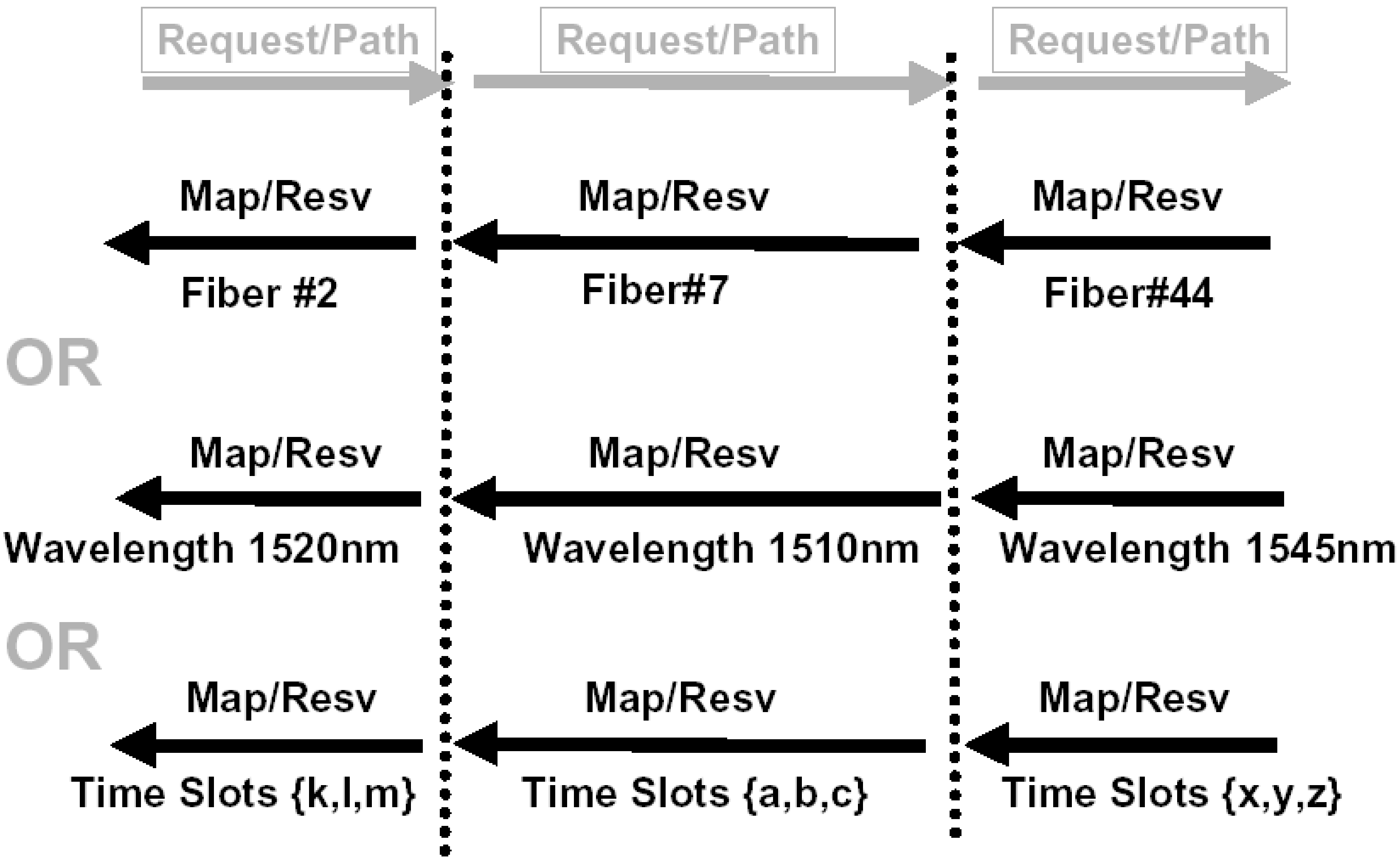
# Lambda Switching



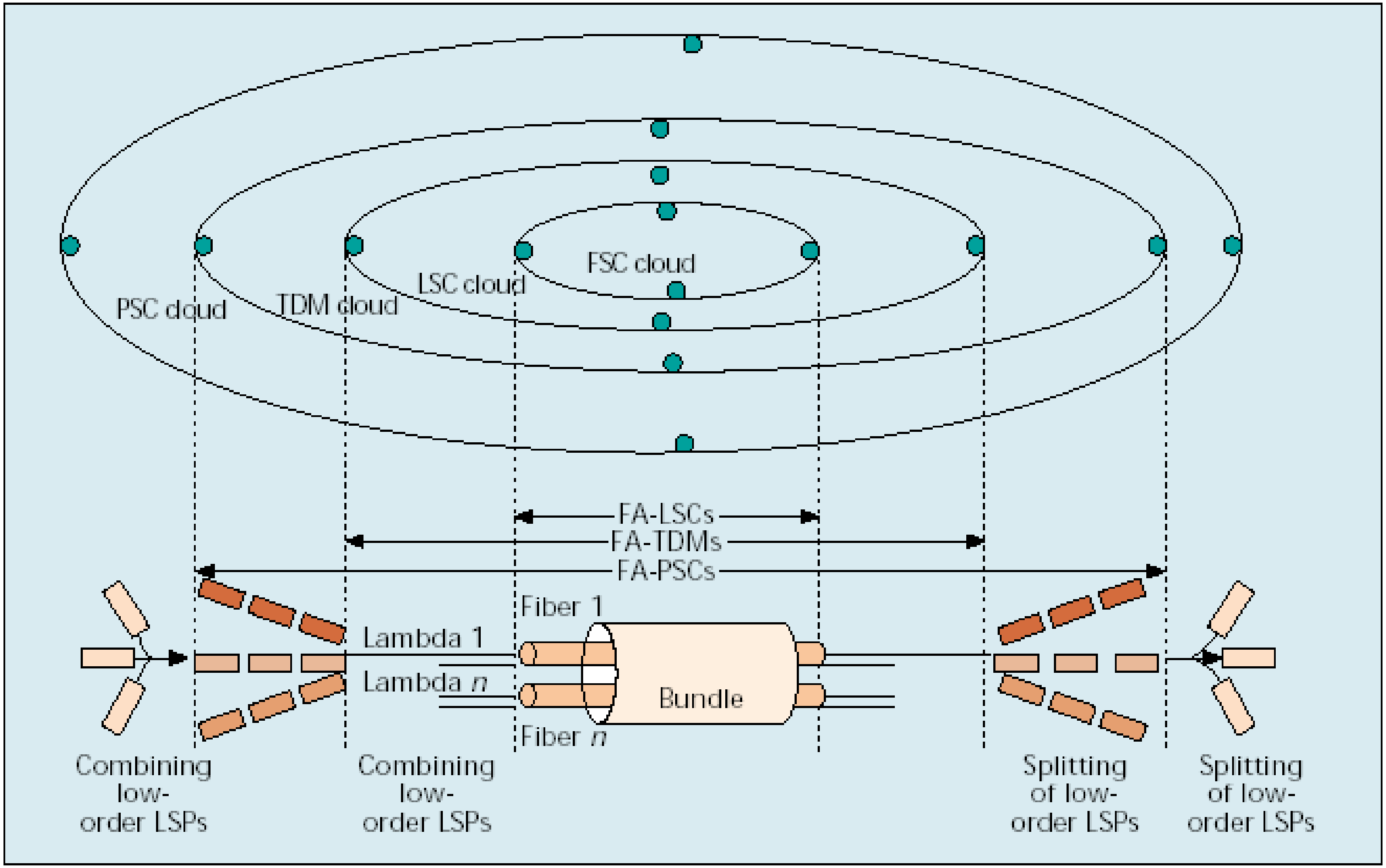
# Port Switching



# "Generalized Labels"



# The GMPLS Hierarchy



# Signaling extensions

- The main GMPLS Signaling Extensions for the control of ITU-G.709 Optical Transport Networks are (RFC 7139 of the IETF):
  - Generalized Label Request
    - *For indicating switching class being requested*
  - Generalized Label
    - *The field to allocate the Label itself, and that can support the four switching classes for SONET/SDH, Ports, Wavelengths and packets*
  - Suggested Label
    - *Suggest a Label, which for certain switching classes (MP$\lambda$S for example) is the optimum*
  - Label Set
    - *Includes a set of labels in the Path Message, from which to mandatorily select the one to be used in the reservation*
  - Upstream Label
    - *Allows to establish bidirectional connections*

# Suggested Label

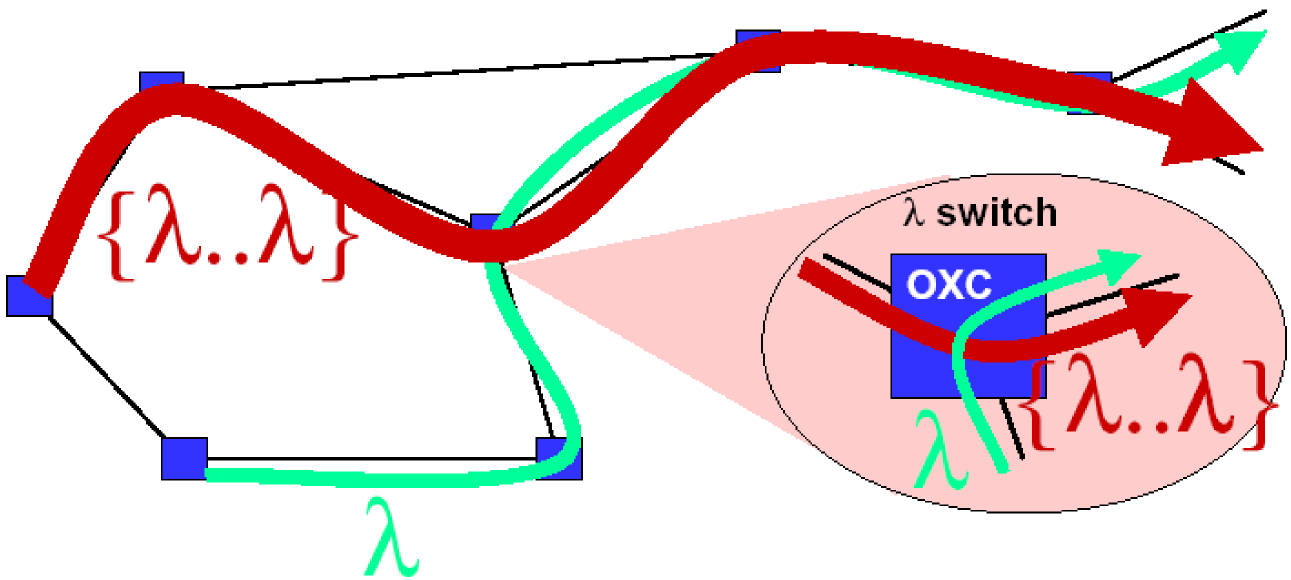
- It is a Generalized Label provided in the upstream PATH/REQUEST messages, which downstream nodes should try to use, and send back in the downstream RESV/MAPPING messages
  - Any way, since is a suggestion, it can be ignored by the downstream nodes
- This feature can help to speed up the establishment of the path in LSRs (e. g., OXCs), which need time to configure the optical switching matrixes
  - If pre-positioned optical switch configuration is made when the request passes by the channels settling time can be reduced

# Label Set

- This extension allows to an upstream node to append a set of Labels to a PATH/REQUEST message with the purpose of restricting the choice of labels from the downstream node
  - It is literally a set of generalized label objects
  - It has a per Hop meaning
- Label Set differs from Suggested Label because the downstream nodes must use one of labels of the set provide upstream

# Label Set

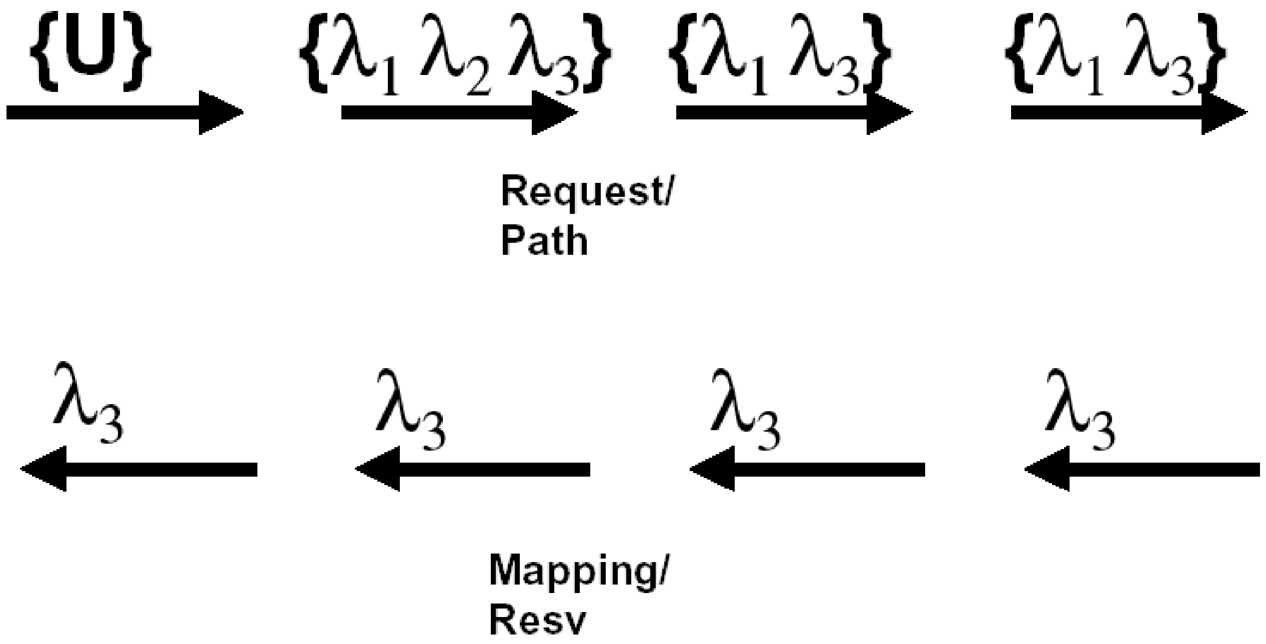
- In the MPλS switching class, the Label Set option avoids to have to perform wavelength conversion, which is highly costly not desirable from the cost point of view




- In terms of MPLS is the same as using the same label in all hops of a LSP

# Label Set

- Example:



# Generalized Label Request

- Object fields and format:
  - LSP Encoding Type: 8 bits
    - *Indicates the LSP encoding being requested, e.g., SDH, PDH, Digital Wrapper, Lambda, Fiber, etc.*
  - Switching Type: 8 bits
    - *Indicates the type of switching that should be performed*
  - G-PID
    - *Identifies traffic (client layer) carried by the LSP*

# Generalized Label

- This new object type travels upstream in the RESV/Mapping messages as the traditional label
  - Consists of a *Link-ID* and a *Label*
- The *Link-ID* is used when from a signaling channel multiple links are controlled
  - The downstream node can assign a *Link ID* and a *Label* (e.g., fiber and wavelength or wavelength and timeslot) per link
  - The *Label* format depends on the kind of link for which the label is used (SONET/SDH, Port, Wavelength etc.)