



## **Tutorial sobre MPLS Multi Protocol Label Switching**

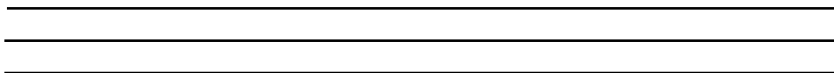
**Ricardo Borrajo**  
Network Architect, NORTEL Networks  
21 Marzo 2001

### **Tutorial outline**

- **A little bit of History and some basic concepts**
- Applications Overview
- Data Plane
- Control Plane
- MPLS and QoS
- Multi-Service over MPLS
- MPLS and VPNs
- MPLS and ASON
- Summary and some MPLS sources of information



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## IP or ATM? That is the question...

- **There is a mixture of IP devices (routers) and ATM&Frame Relay switches, making today data networks.**
  - IP is the only survivor among all the layer 3 protocols (DECnet, IPX, AT,...)
  - ATM was chosen because its high speeds (up to OC-48/2.5 Gbps) and its inherent Quality of Service.
- **But mixing both was complex and redundant in some features such as Flow Control, addressing, management,....**
- **IP has some serious shortcomings:**
  - The size of IP routing Tables is increasing and slows down the forwarding decisions when using hop-by-hop routing.
  - IP datagram “always” follows the “shortest IP path”, so alternative paths are not fully used.
- **But also great advantages:**
  - QoS is becoming much better (DiffServ)
  - Terabit routers at OC-192&OC-768 speeds are on its way

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## ATM or IP? That is the question...

- **ATM has several important drawbacks:**
  - ATM has lost the battle at the desktop, at the backbone campus and ...
  - Tax cell (5 bytes from 53 bytes -> ~ 2 x OC-3 in OC-48 links)
  - Serious SAR speed limitations at OC-48 rates
- **But also great ideas that can be reused:**
  - The circuit-oriented approach for fast-switching cells just swapping the VPI/VCI “labels”
  - The possibility to establishing paths based on traffic and not mandatory the “shortest path”
  - And of course, Quality of Service (QoS)
- **Running IP over ATM directly (RFC 1577) is not the best solution.**
- **So it is not strange that some people began to simplify the ATM layers and get a “mixture” of both worlds (IP and ATM)**

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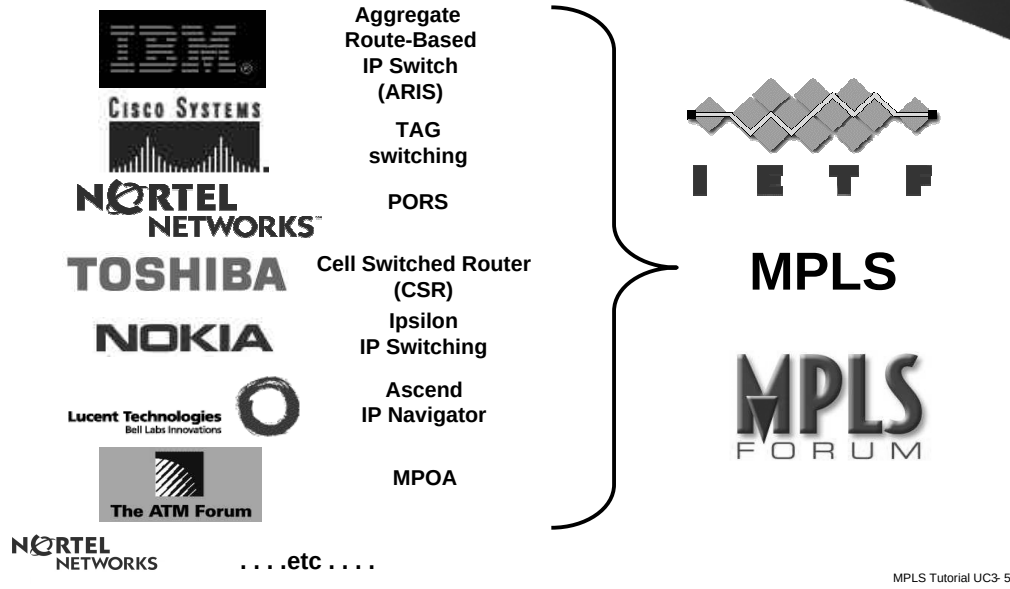
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## The origins of MPLS (first draft in 1997)



## MPLS comes into place

- **MPLS is a serious attempt to really and definitely unify the good things in ATM with the good thing in IP.**
- **Actual telecommunications manufacturers, are now typically the result of a merger between ATM and IP companies:**
  - Cisco (IP) & Stratacom (FR/ATM)
  - LUCENT => Ascend (IP) & Cascade (FR/ATM)
  - NORTEL => Bay Networks (IP) & Northern Telecom (FR/ATM)
- **With time, MPLS will replace Frame Relay, ATM and even IP as the core switching technology on large networks... but in a smooth way (for ex. VoATM)**

## So what is MPLS?

- There is quite a lot of confusion about MPLS, mainly because it is a new technology and also because it uses terms and protocols from other technologies such as IP and ATM.
- MPLS is a way of encapsulating ANY layer3 protocol packet and using a label switching technique, route/switch this packet all along its way to its final destination, regardless of the L3 addressing inside the packet.
- So it is frame-based circuit-oriented technology (but no FR)
- MPLS is a switching/routing technique, but it is also:
  - a way to traffic engineer large networks,
  - another way for building IP VPNs,
  - a Quality of Service mechanism, etc,...
- And tries to get the best of both worlds (IP and ATM)

## MPLS or IPLS?

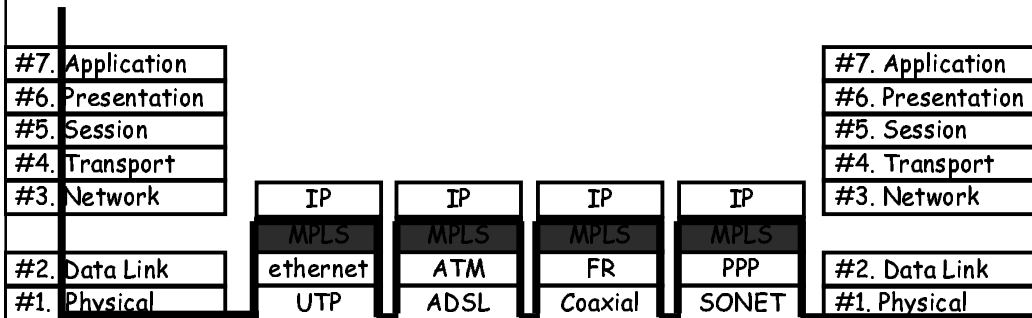
- Although MPLS has been designed to work with any layer 3 protocol, most probably we shall only see the IP part of MPLS implemented (very much like MPOA)
- MPLS seats at layer 2½ in the OSI Reference Model, just between the Data Link and Network layers.
- The good thing is that no matter the data link layer it seats below, MPLS frames (no cells) can travel over any media: ATM, Frame Relay, Ethernet 10/100/1000, POS (Packet Over SONET),...

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## MPLS position on the OSI Ref Model



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## IP Header vs ATM NNI header vs MPLS Label

### IP Header

|                        |          |                 |                 |
|------------------------|----------|-----------------|-----------------|
| 0                      | 8        | 16              | 31              |
| VERS                   | HLEN     | Service Type    | Total Length    |
| Identification         |          | Flags           | Fragment Offset |
| TTL                    | Protocol | Header Checksum |                 |
| Source IP Address      |          |                 |                 |
| Destination IP Address |          |                 |                 |
| Options                |          |                 | Padding         |

### ATM NNI Header

|     |    |     |    |     |     |
|-----|----|-----|----|-----|-----|
| 0   | 12 | 28  | 31 | 32  | 39  |
| VPI |    | VCI |    | PTI | CLP |
|     |    |     |    | HEC |     |

### MPLS Label

|       |   |    |       |
|-------|---|----|-------|
| 0     | 8 | 16 | 31    |
| Label |   |    | Exp S |
|       |   |    | TTL   |

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

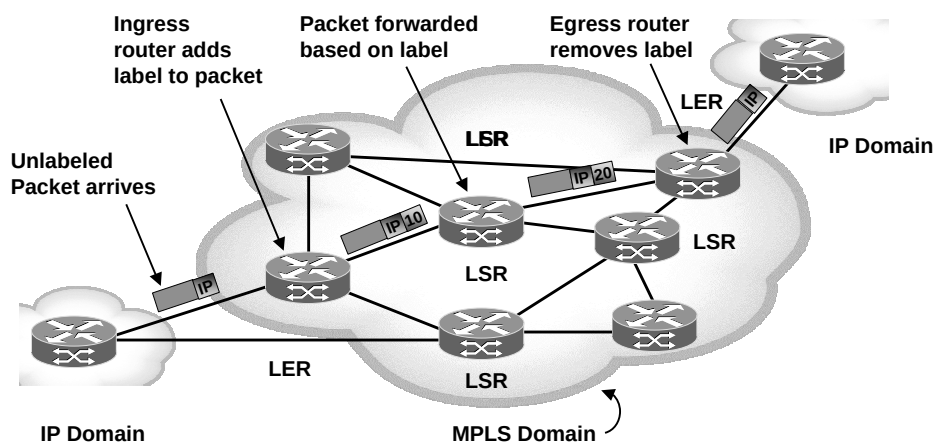
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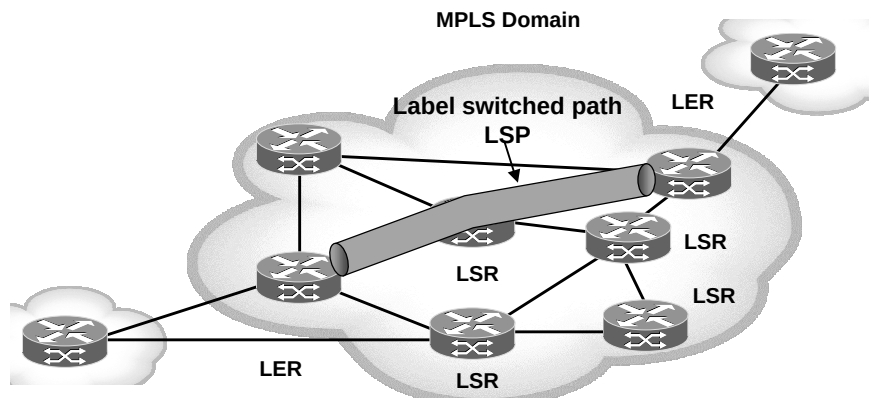
## Terminology

- **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

## How MPLS works...



## How MPLS works...



- 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 in packet

## MPLS Edge and Core

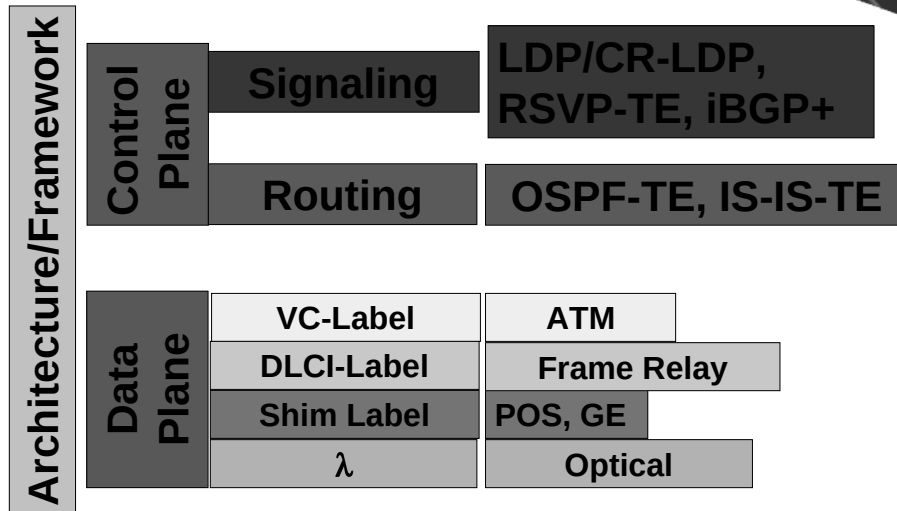
- In MPLS is important so underline the great difference between the edge (IP to MPLS) and the core (MPLS to MPLS)
- At the core, the only important thing is to switch frames (or cell if using ATM) very fast, but the high level info (including IP are hidden from the LSRs)
- At the edge (aggregation point), IP is still visible, as well as all the information regarding the application and user.
- So it is at the edge of the MPLS cloud where things like DS marking, filtering, authentication, firewalling, NAT, cache redirection, etc,... are performed.

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## What is Standard MPLS?



## A label by any other name ...

- **There are many examples of label substitution protocols already in existence**
  - ATM: label is called VPI/VCI and travels with cell
  - Frame Relay: label is called a DLCI and travels with frame
  - TDM: label is called a timeslot its implied, like a lane
  - X25: a label is an LCN
  - proprietary PORS (Path Oriented Routing System/NOTEL), TAG (Tag Switching/Cisco), etc.
  - frequency substitution: where label is a light frequency via DWDM, OXC etc.

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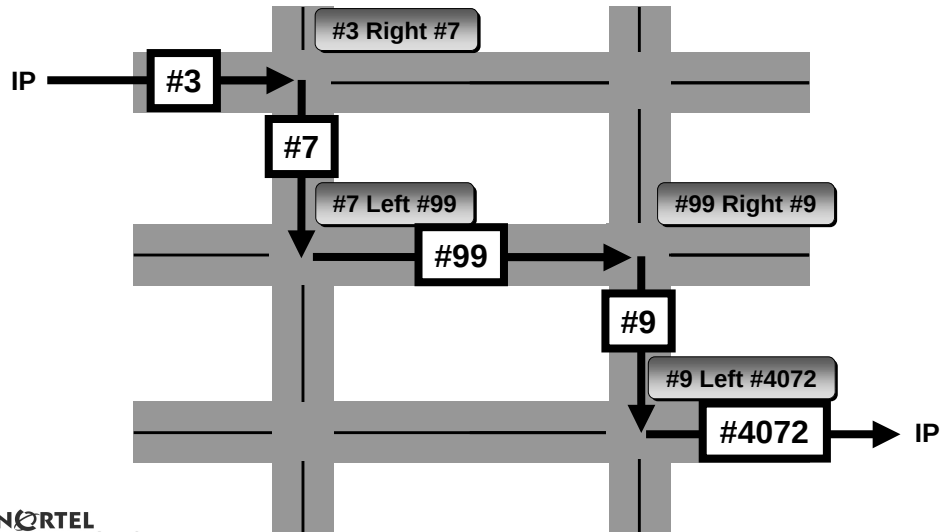


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## Label Switched Path



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## Label Switched Paths (LSPs)

### LSPs ...

- Are often called “tunnels”
- Are always unidirectional
- Can be either:
  - point-to-point, or
  - merging

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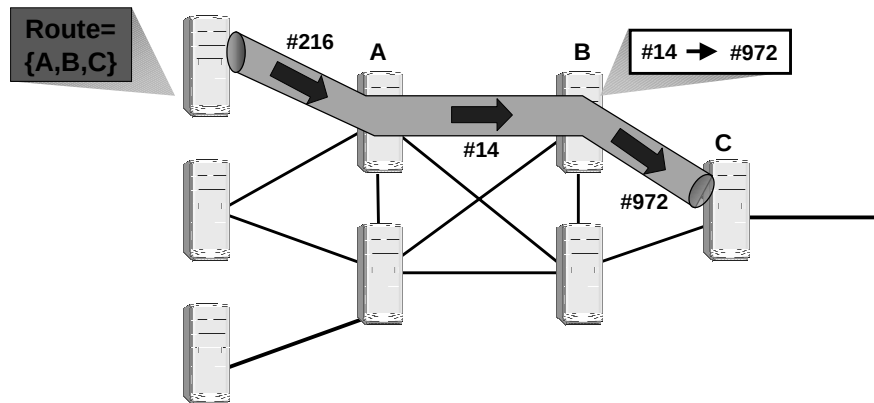
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## Point-to-point LSP

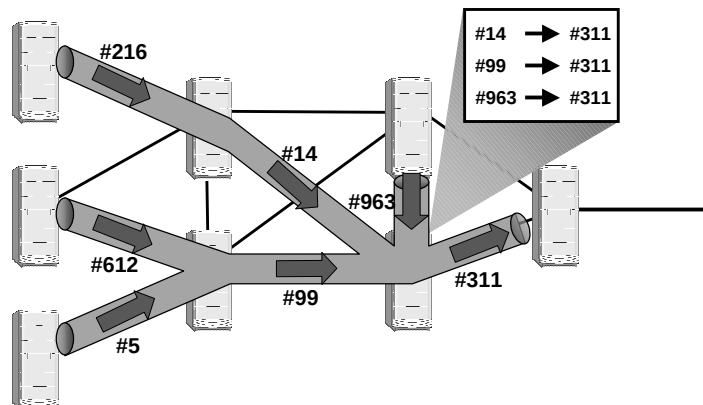


- LSP follows route that source chooses. In other words, the control message to establish the LSP (label request) is *source routed*.

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## Merging LSP



- LSP forms a "sink tree"
- The branches of the LSP always follows the same route as normal IP forwarding; that is, the *shortest path*

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- A little bit of History and some basic concepts
- **Applications Overview**
- Data Plane
- Control Plane
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- MPLS and VPNs
- MPLS and ASON
- Summary and some MPLS sources of information

## Applications of MPLS

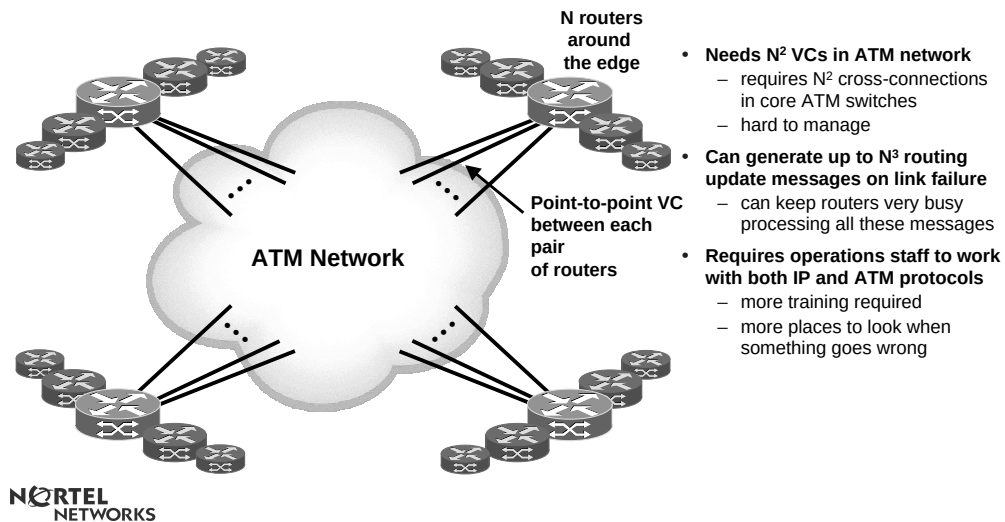
- A Unified IP/ATM solution
- Network-Based Virtual Private Networks
- Multi Service over MPLS
- IP Traffic Engineering
- Automatically Switched Optical Networks (ASON)
- Replacing iBGP in core routers

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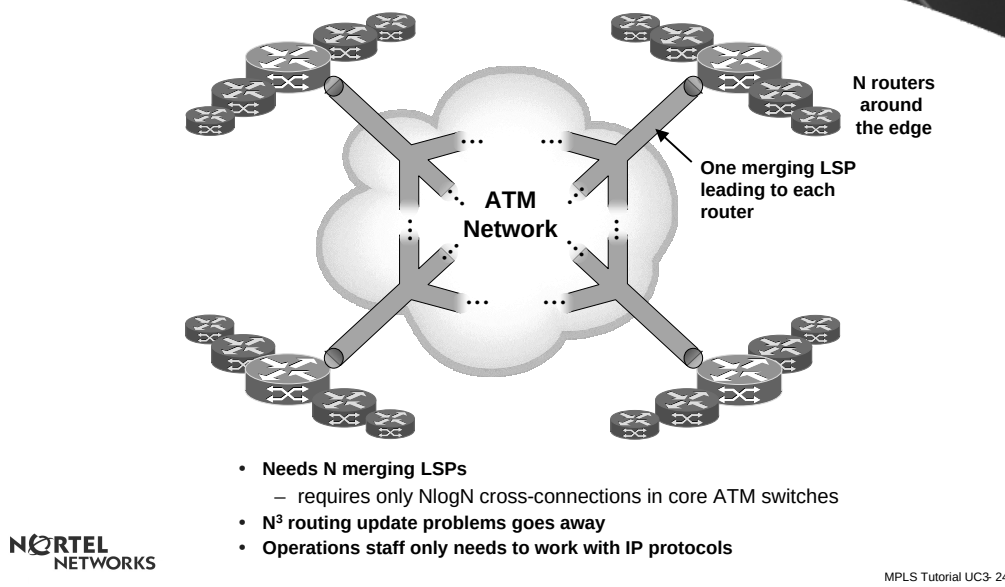
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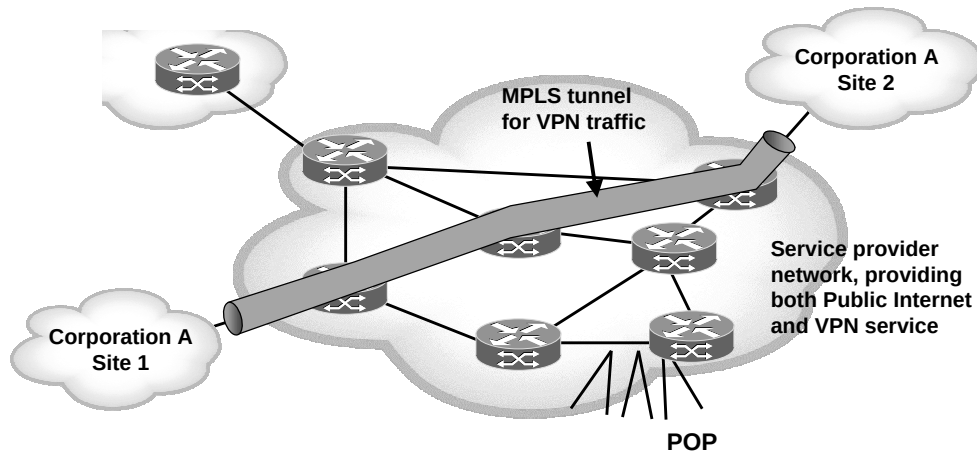
## Unified IP/ATM solution –Problem Definition



## Unified IP/ATM with MPLS



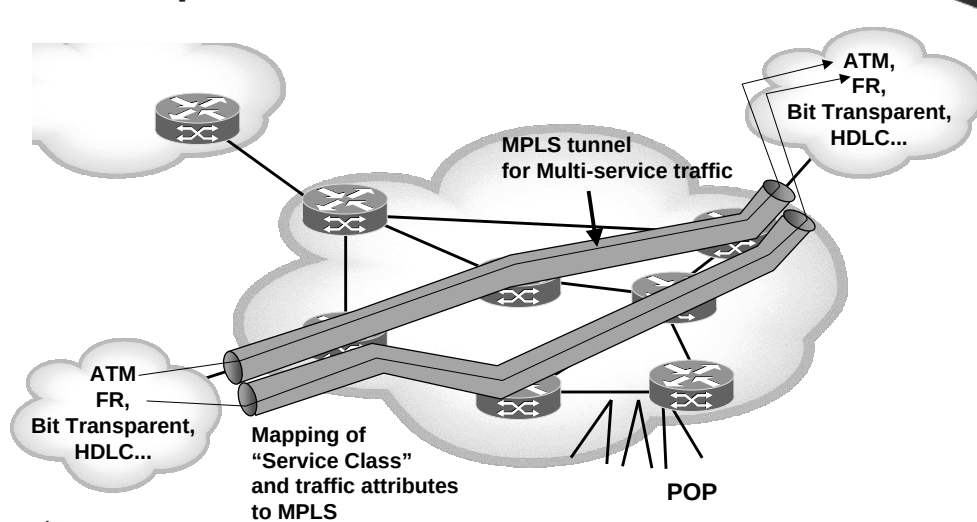
## Network-Based Virtual Private Networks using MPLS



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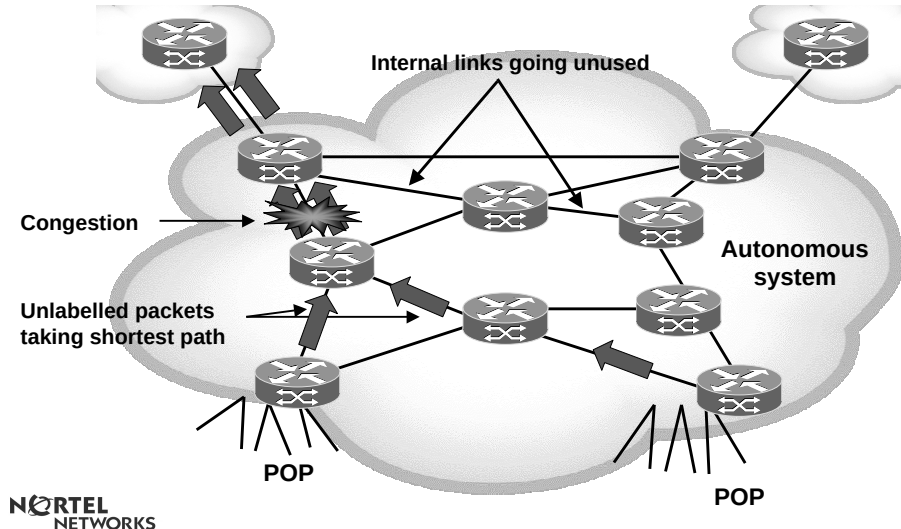
## Multi-protocol Over MPLS



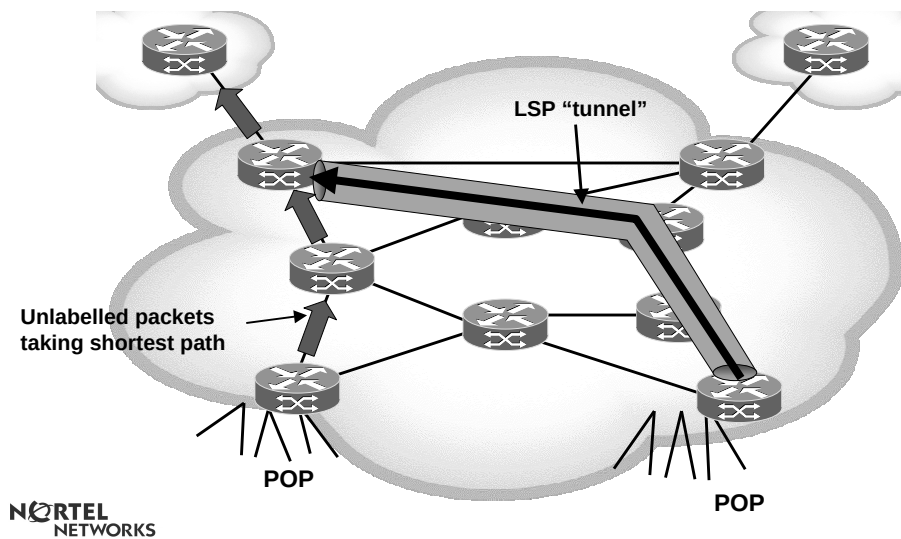
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## IP Traffic Engineering –Problem Definition



## Traffic Engineering using MPLS

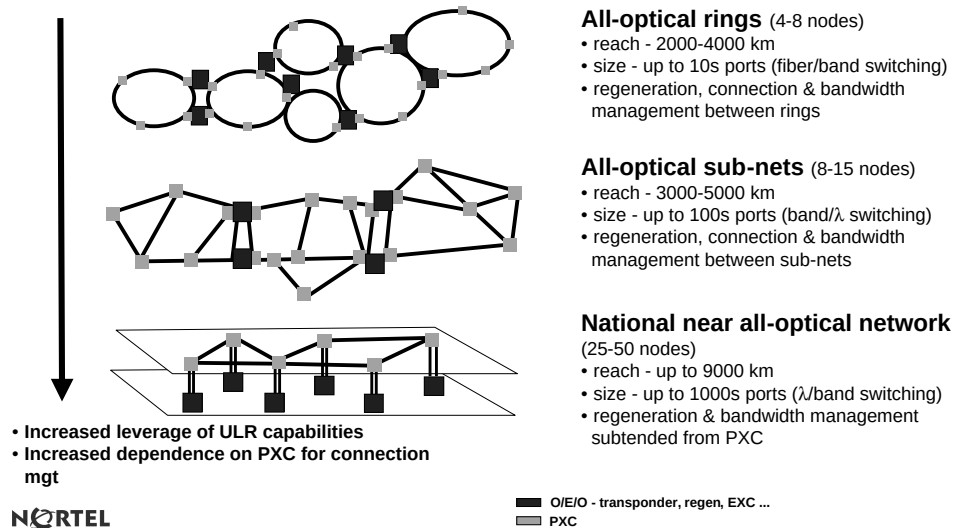


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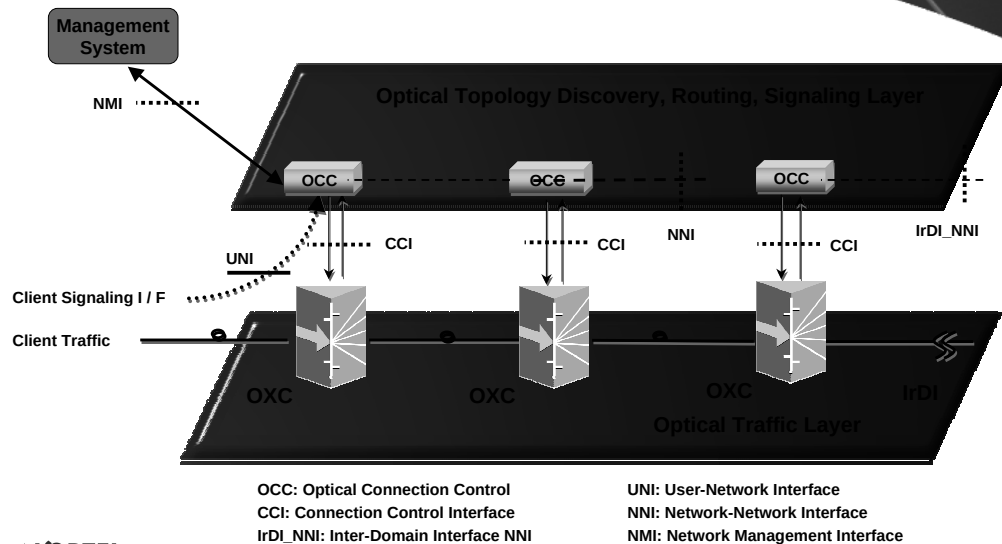
## All-Optical Networking - Impact of Optical Reach



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## G.ASON's Open Architecture

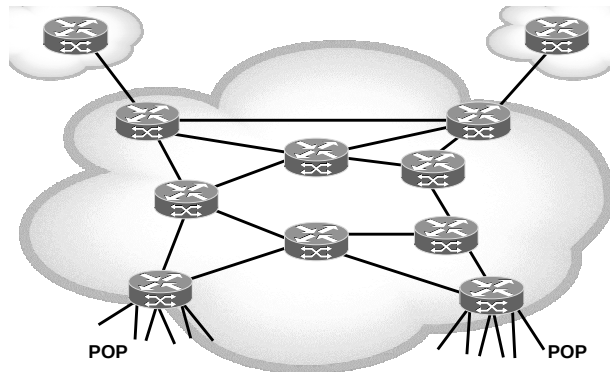


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## Replacing iBGP on interior routers

### – The problem



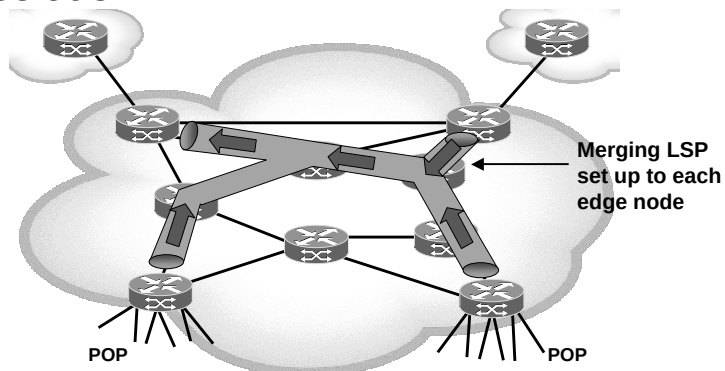
- All routers in the network run both iBGP and OSPF/IS-IS
- Running iBGP on lots of routers makes reaction to routing changes slower

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## Replacing iBGP on interior routers

### – The solution



- Interior routers run only OSPF/ISIS; edge routers still run both
- iBGP not needed because packets are traveling on an LSP
  - Interior router forwards the packet based on the label
  - No knowledge of external destinations needed, hence no iBGP

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## Data Plane

- **Label Encapsulations**
- Label Stacking

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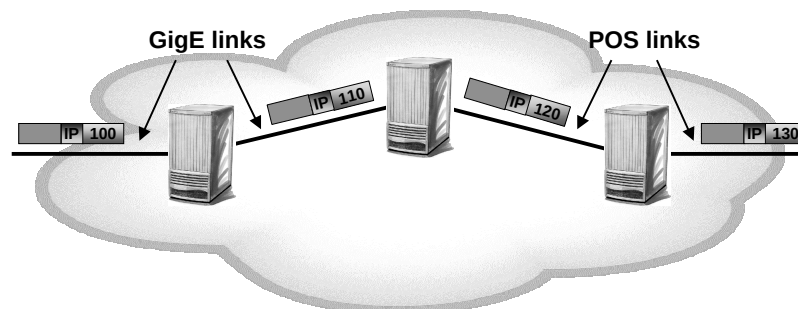
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## Important media types for MPLS today

- Packet over SONET (PoS) and Gigabit Ethernet (GigE)
- ATM with Shim Headers
- ATM with VPI/VCI Labels
- Frame Relay
- Optical

## PoS and GigE



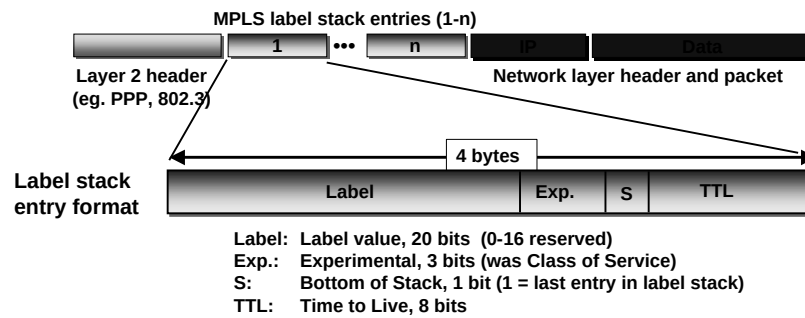
- “Packet over SONET” is really IP over PPP over SONET
- Gigabit Ethernet is really IP over Ethernet (running at gigabit speeds)
- Label is inserted before IP header

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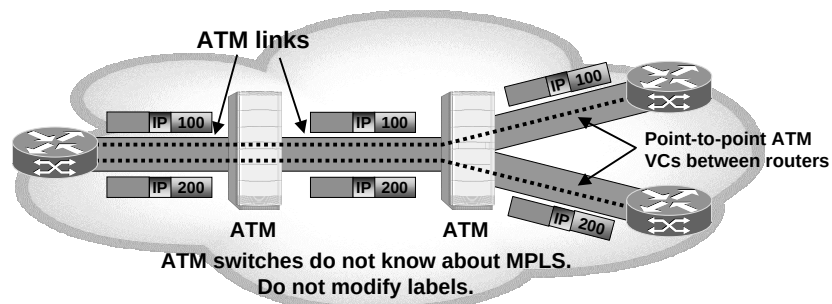
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## MPLS encapsulation – PPP & Ethernet links



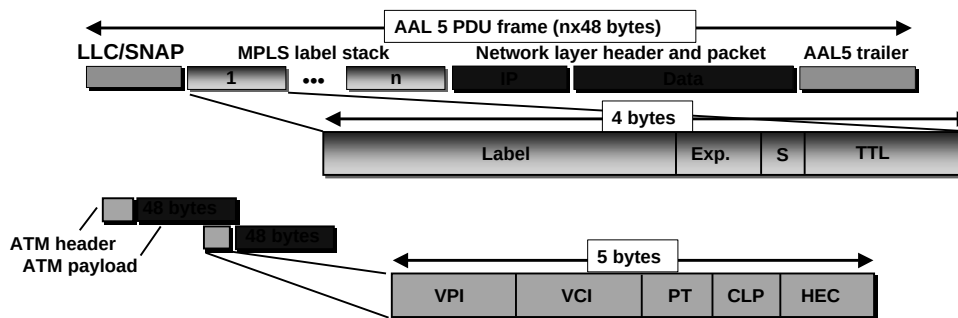
MPLS on PPP and Ethernet links uses a label stack (shim header) inserted between Layer 2 and Layer 3 headers

## ATM with Shim Headers



- Designed for existing router and ATM switch networks
- Routers connected by point-to-point ATM VCs
- IP packet has label prepended
- This method does not solve  $N^2$  and  $N^3$  problems mentioned earlier

## MPLS encapsulation – ATM with Shim Headers

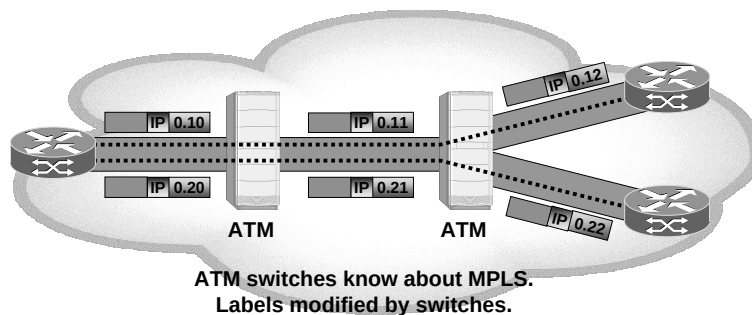


- Labels carried in Label Stack; top label not modified by ATM switches
- VPI/VCI field identifies ATM VC
- LLC/SNAP identifies protocol that follows as "MPLS"
- This format heavily used, but not officially documented

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## ATM with VPI/VCI Labels



- This method intended to solve  $N^2$  and  $N^3$  problems
- ATM switches enhanced to know about MPLS
- Labels carried in VPI/VCI field to allow switches to modify

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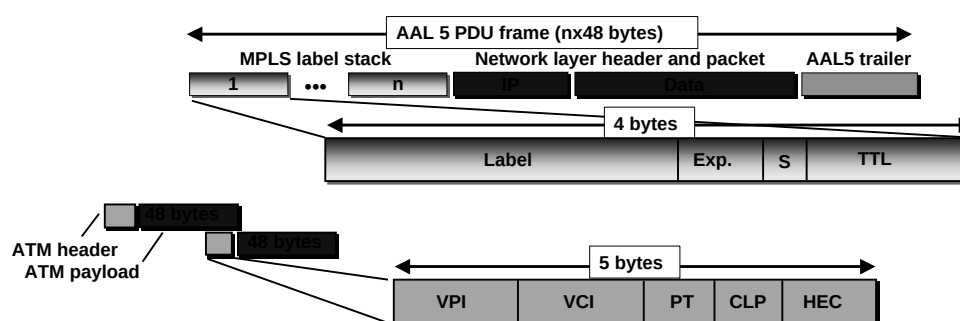
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## ATM Switch Enhancements

- **Data Plane -- No change required**
  - Data plane cannot tell difference between a VC and an LSP
- **Control Plane -- Add IP routing and MPLS signaling**
  - VCs are signaled using PNNI signaling
  - VCs are routed using PNNI routing
  - LSPs are signaled using MPLS signaling
  - LSPs are routed using IP routing

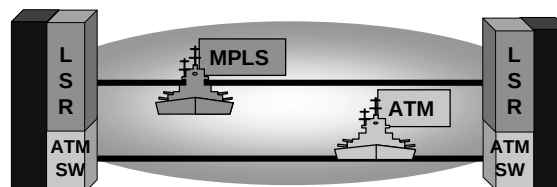
## MPLS encapsulation

– ATM with VPI/VCI labels



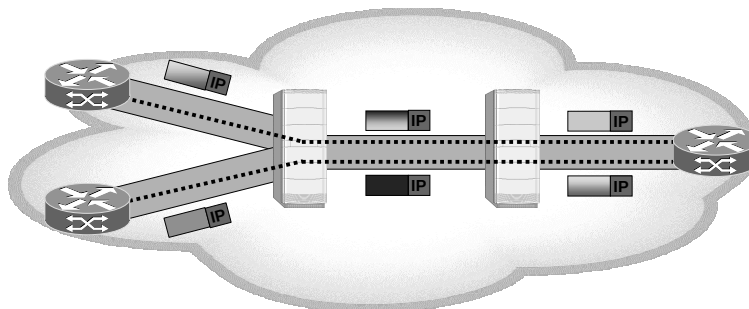
- Top label value carried in VPI/VCI field of ATM header
- Top label stack entry contains a "0" in label field
- 2..n labels carried in label field of subsequent label stack entries

## Ships in the Night



- ATM Forum and MPLS control planes both run on the same hardware but are isolated from each other, i.e. they do not interact
- This allows a single device to simultaneously operate as both an MPLS LSR and an ATM switch
- Important for migrating MPLS into an ATM network

## Optical



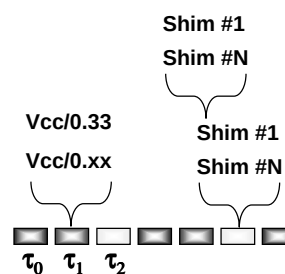
- Label not prepended to packet
- Instead is represented by a fiber number or a wavelength

## Data Plane

- Label Encapsulations
- Label Stacking

## MPLS - Label Hierarchy

StatMux TimeSlot



Wavelength

$\lambda$   $\{\lambda.. \lambda\}_1$

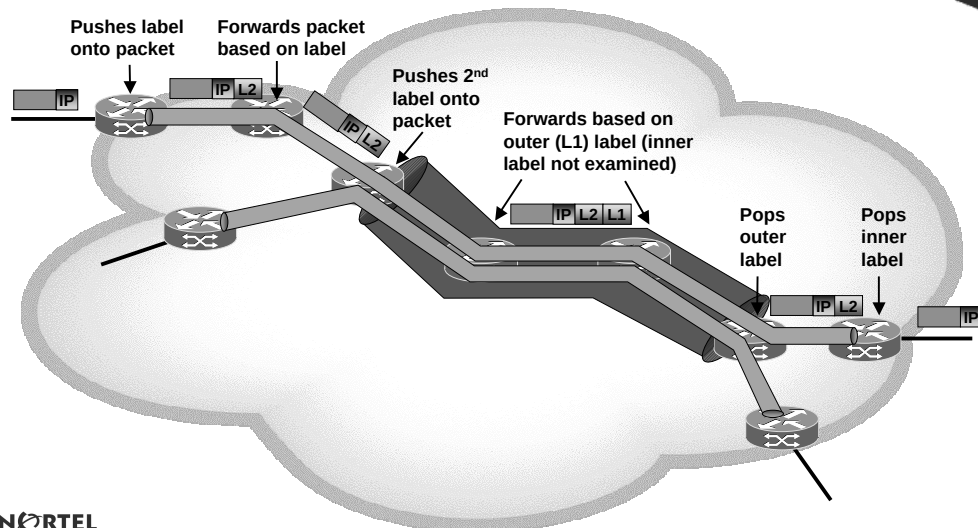
Waveband

Fiber Bundle

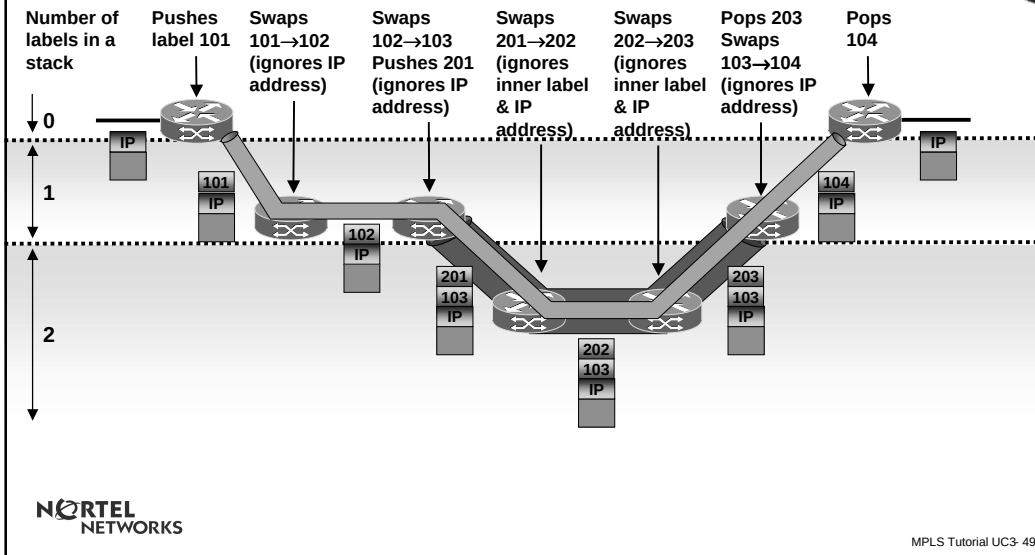
## LSPs within LSPs

- **Can put LSPs inside other LSPs**
  - Very powerful – provides scalability
- **Implemented by allowing packet to have more than one label at a time**
  - Labels form a stack
- **Router always forwards based on outermost or “top” label**
- **Can nest LSPs in this way to arbitrary depth**
  - 2 or 3 is maximum we see today

## Label Stacking Example



## Label Stacking Details



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## Control Plane

- **Signaling**
  - LDP
  - CR-LDP and RSVP-TE
- **Constraint-based Routing**

## Terminology

- **Officially, LDP = “Label Distribution Protocol”**
- **Many people prefer:**
  - “Label Distribution Protocol” -- Generic term**
  - “LDP” -- One specific example**

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## LDP: Uses

- **Creates merging LSPs**
- **LSPs follow same route as unlabelled packets**
- **No way to specify bandwidth or other traffic parameters**
- **Useful for:**
  - fast IP-aware forwarding over ATM
  - reducing routing table size on interior routers
  - creating VPN tunnels
- **Not useful for:**
  - traffic engineering

## Terminology: FEC

- **FEC = “Forwarding Equivalence Class”**
- **Formally, a FEC is the set of packets that are forwarded in the same manner by a router**
- **For example, the set of packets that are traveling on an LSP**
- **However, because of the way LDP is used today, it can be thought of as the IP address of the router at which the LSP terminates**

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## LDP: Modes of operation

- To run LDP, must make three mode choices:
  - Downstream-on-Demand or Downstream Unsolicited ?  
(the distribution mode)
  - Liberal or Conservative ?  
(the label retention mode)
  - Ordered or Independent ?  
(the control mode)
- Combinations of choices are possible

## Label distribution - methods

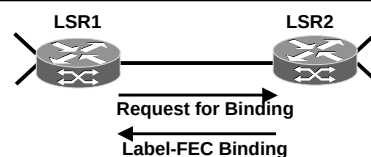
Label distribution can take place using one of two possible methods:

### Downstream Unsolicited Label Distribution



- LSR2 and LSR1 are said to have an "LDP adjacency" (LSR2 being the downstream LSR)
- LSR2 generates a label for the FEC and communicates the binding to LSR1
- LSR1 inserts the binding into its forwarding tables
- If LSR2 is the next hop for the FEC, LSR1 can use that label knowing that its meaning is understood

### Downstream-on-Demand Label Distribution

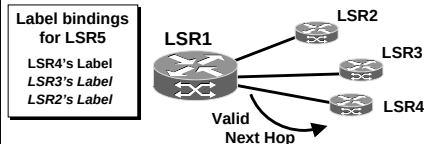


- LSR1 recognizes LSR2 as its next-hop for an FEC
- A request is made to LSR2 for a binding between the FEC and a label
- If LSR2 recognizes the FEC and has a next hop for it, it creates a binding and replies to LSR1
- Both LSRs then have a common understanding

Both methods are supported, even in the same network at the same time  
For any single adjacency, LDP negotiation must agree on a common method

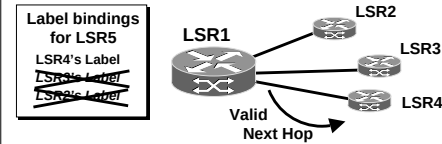
## Label retention methods

### Liberal Label Retention



- LSR maintains bindings received from LSRs other than the valid next hop
- If the next-hop changes, it may begin using these bindings immediately
- May allow more rapid adaptation to routing changes
- Requires an LSR to maintain many more labels

### Conservative Label Retention



- LSR only maintains bindings received from valid next hop
- If the next-hop changes, binding must be requested from new next hop
- Restricts adaptation to changes in routing
- Fewer labels must be maintained by LSR

Label retention method trades off between label capacity and speed of adaptation to routing changes

## Control Plane

- **Signaling**
  - LDP
  - CR-LDP and RSVP-TE
    - common features
    - CR-LDP details
    - RSVP-TE details
    - comparison
- **Constraint-Based Routing**

## CR-LDP and RSVP-TE

- **CR-LDP = “Constraint-Routed LDP”**
- **RSVP-TE = “RSVP with Traffic Engineering Extensions”**
- **From a user’s prospective, these two protocols provide essentially the same function**

## CR-LDP and RSVP-TE: Uses

- **Used to set up point-to-point LSPs**
- **LSPs can follow any path**
- **Can specify QoS parameters for LSP**
- **Useful for:**
  - Traffic Engineering of Public Internet traffic
  - Traffic Engineering of VPN tunnels

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## Common features

- Operate in (Downstream-on-Demand, Conservative, Ordered) mode
- Important Features:
  - Explicit route
  - QoS specification
  - LSP preemption
  - LSP modification
- Also, LDP sets up LSPs automatically, while CR-LDP and RSVP-TE typically require some sort of external intervention

## Common features: Explicit route

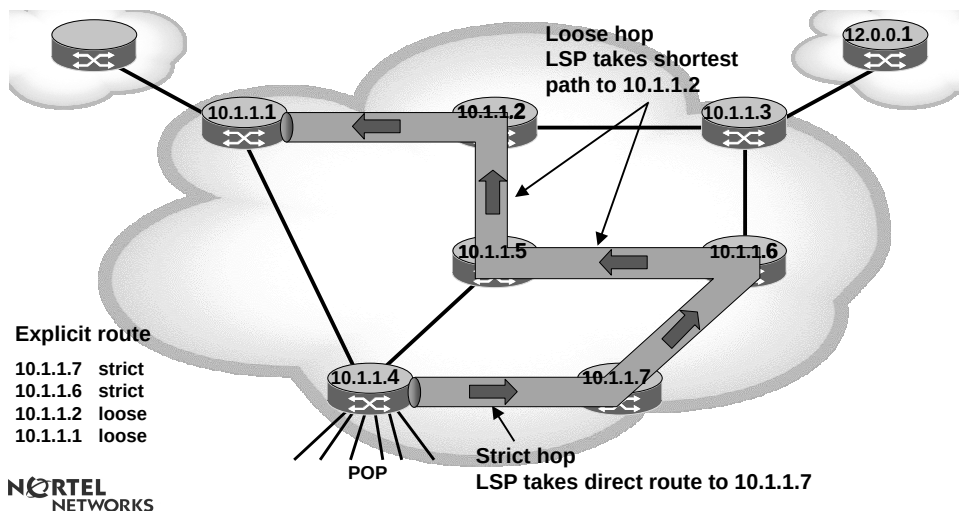
- LSP route is specified as a sequence of router addresses
- Each hop between two routers in the path is either:
  - Strict if the two routers must be directly connected
  - Loose if other routers may appear in between
- On loose hops, the route taken between the nodes is the shortest path (as indicated by the routing table)
- The simplest explicit route is a single loose hop from the ingress router to the egress router

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## Common features: Explicit route example



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## Common features: QoS specification

- Can specify resources to allocate to LSP
  - example is the bandwidth to reserve on each link
- In general, QoS specified using token buckets
- The simplest QoS specification is to simply request Best Effort service, in which case no resources are allocated

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## CR-LDP details

- CR-LDP is an extension to LDP
- Like LDP, runs over TCP
- Uses existing LDP messages, but defines additional TLVs for the messages

## RSVP-TE details

- RSVP-TE is an extension of “classical” RSVP
- Runs directly over IP
- Uses Path messages (= Label Request) and Resv messages (= Label Mapping)
- Extends classical RSVP with new objects (= TLVs) for these messages

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## RSVP-TE details: Classical RSVP

- **Designed in early 90's**
- **Makes QoS reservations between hosts**
  - for example, between a server and a workstation
- **Has no concept of labels and LSPs**
  - packets assumed to travel unlabelled
- **No explicit route concept; reservations made along shortest path**

## RSVP-TE details: Differences from classical RSVP

- **Concept of labels and LSPs**
- **Explicit routes**
- **LSP attributes (including Setup and Holding priorities)**
- **“make-before-break” modification**
- **Record route**  
(record the route of an LSP set up with loose hops)

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## RSVP-TE details: QoS specification

- Based on integrated services (int-serv) model
- Three service classes:
  - Class-of-service: LSP provides best-effort service
  - Guaranteed Load: LSP provides hard delay bounds
  - Controlled Load: LSP provides good service, but no hard delay bounds

## RSVP-TE details: Soft state

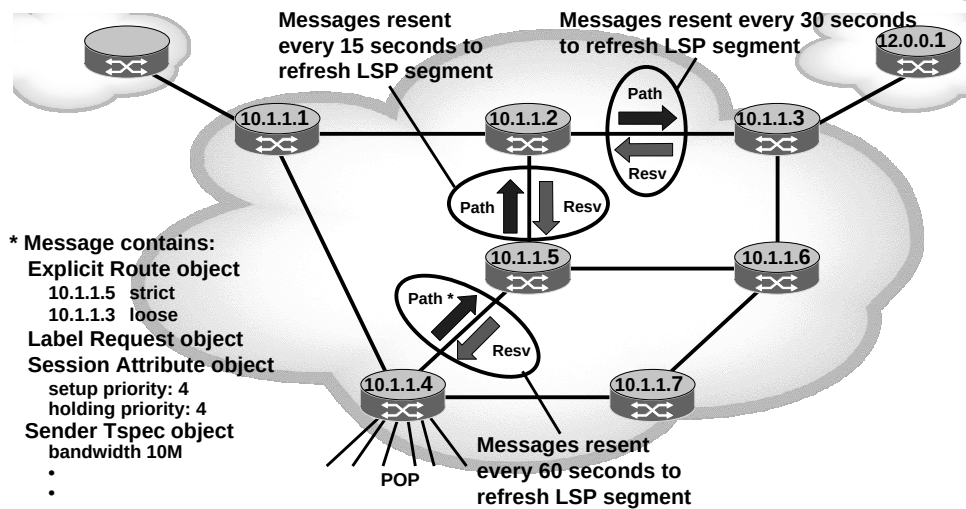
- RSVP-TE (like classical RSVP) is a soft-state protocol
- Path and Resv messages must be resent to refresh the LSP and keep it alive
- This serves two purposes:
  - RSVP-TE runs directly over IP, so resending makes sure the information gets through even if some messages are lost
  - no need to explicitly tear down an LSP -- just stop refreshing it instead
- Messages resent on a per-hop basis, not end-to-end

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## RSVP-TE details: Example



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## RSVP-TE details: Refresh reduction

- Each Path and Resv message must be refreshed
- In a network with many LSPs, this requires lots of messages
- Hence the Refresh Reduction Extension
- This allows a router to send a single compact message that refreshes lots of LSPs at once

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## CR-LDP and RSVP-TE comparison

|             | CR-LDP                                                                | RSVP-TE                                                                     |
|-------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------------|
| Based on    | LDP                                                                   | Classical RSVP                                                              |
| Messages    | Request →<br>← Mapping                                                | Path →<br>← Resv                                                            |
| Transport   | Runs over TCP                                                         | Runs over IP                                                                |
| State model | Hard state<br>– explicit setup<br>– no refresh<br>– explicit teardown | Soft state<br>– explicit setup<br>– refresh required<br>– implicit teardown |

## CR-LDP and RSVP-TE comparison

|                   | CR-LDP                         | RSVP-TE                        |
|-------------------|--------------------------------|--------------------------------|
| Explicit Route    | Strict and loose routes        | Strict and loose routes        |
| QoS Specification | ATM-TM model                   | Int-serv model                 |
| LSP Preemption    | 8 setup and holding priorities | 8 setup and holding priorities |
| LSP Modification  | Make-before-break method       | Make-before-break method       |

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## CR-LDP and RSVP-TE comparison

|                    | CR-LDP                           | RSVP-TE                         |
|--------------------|----------------------------------|---------------------------------|
| Early Adopters     | Nortel, Sycamore                 | Cisco, Juniper                  |
| Supporters         | Host of others                   | Host of others                  |
| Notable Points     | New Protocol<br>Simpler Protocol | Poorly Specified                |
| Notable Challenges | Interoperability                 | Interoperability<br>Scalability |

Nortel is Developing Both

## Tutorial outline

- A little bit of History and some basic concepts
- Applications Overview
- Data Plane
- Control Plane
- **MPLS and QoS**
- Multi-Service over MPLS
- MPLS and VPNs
- MPLS and ASON
- Summary and some MPLS sources of information

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**¿Se quiere QoS? Pues MAS ancho de banda**



## **MPLS & QoS**

- **Emerging QoS Requirements**
- **ATM QoS**
- **IP QoS**
- **MPLS QoS**
- **Example Applications**

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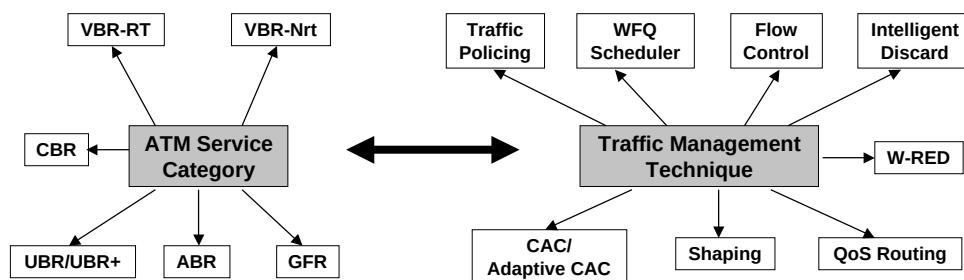
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## Emerging QoS Requirements

- Enable the offering of multiple services with various soft and hard guarantees:
  - ATM Service Categories
  - Leased Line / Circuit Emulation
  - Premium VPNs
  - Class-based VPNs
  - DiffServ
  - Voice over IP
- Enabling making trade-offs between cost, scalability, complexity, and guarantees/SLAs

## ATM Traffic Management



- Support a Rich Set of QoS Capabilities
- Provide Hard Guarantees on loss, delay, and delay variance
- Trade off on network complexity and network scalability
- Limited aggregation using VPs and Differentiated UBR and UBR+

## Soluciones Estándar del IETF para QoS

Dos aproximaciones y dos soluciones diferentes:

- **Reserva de Recursos:** Integrated Services (IntServ)
- **Priorización:** Differentiated Services (DiffServ)

### I. Servicios Integrados (IntServ):

- \* Se identifica un flujo de aplicación y se le reservan y mantienen los recursos a lo largo de la Red.
- \* Las aplicaciones reciben gestión de QoS apropiada.
- \* Uso apropiado sólo para redes pequeñas o cerca de la frontera de la red.

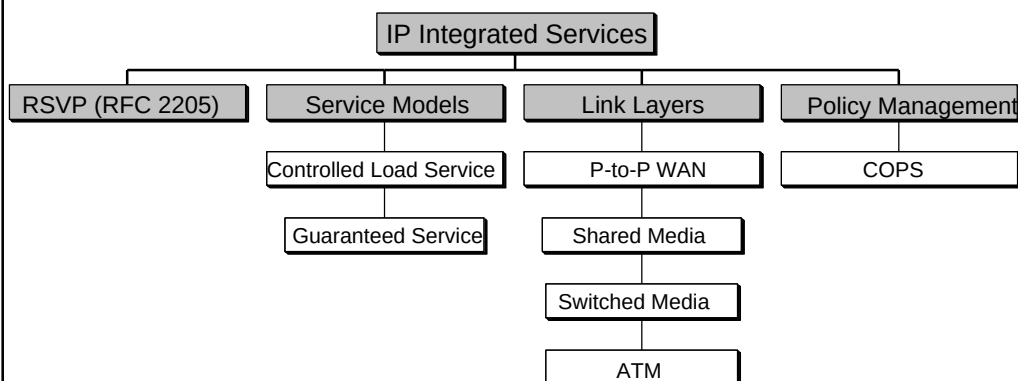
- Filosofía similar a la reserva de recursos en la red de Telefonía.
- Crea problemas de crecimiento y dimensionamiento en el núcleo de la red.

### II. Servicios Diferenciados (DiffServ)

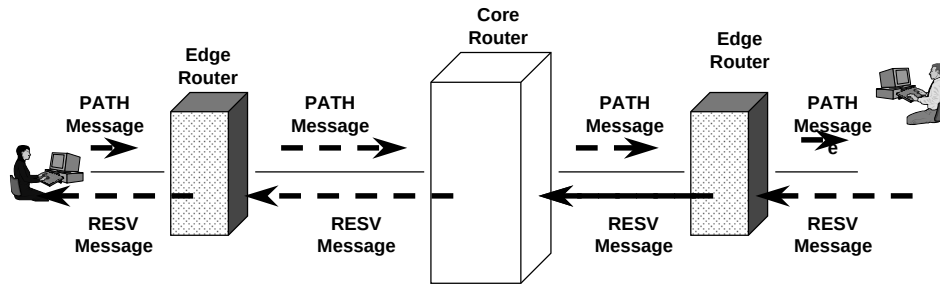
- \* No se identifican "flujos" sino paquetes.
- \* No se reservan recursos de antemano.
- \* El tratamiento acelerado se realiza salto-a-salto, y paquete-a-paquete.

- Capacidad de crecimiento
- Su efectividad disminuye a medida que crece el tráfico definido como de alta prioridad.

## Arquitectura de Servicios Integrados (IntServ)

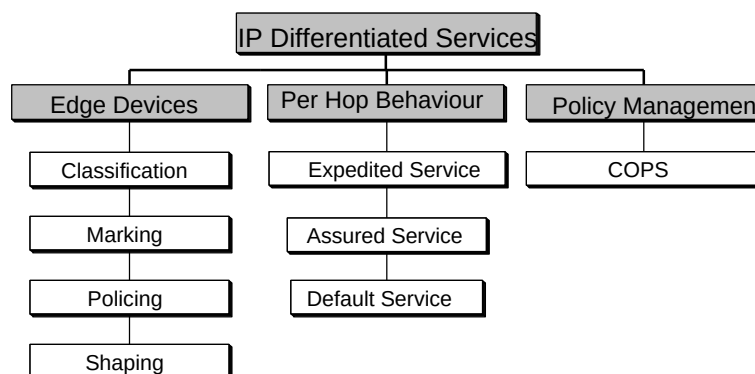


## IP QoS Mechanisms-1: Int-Serv Architecture



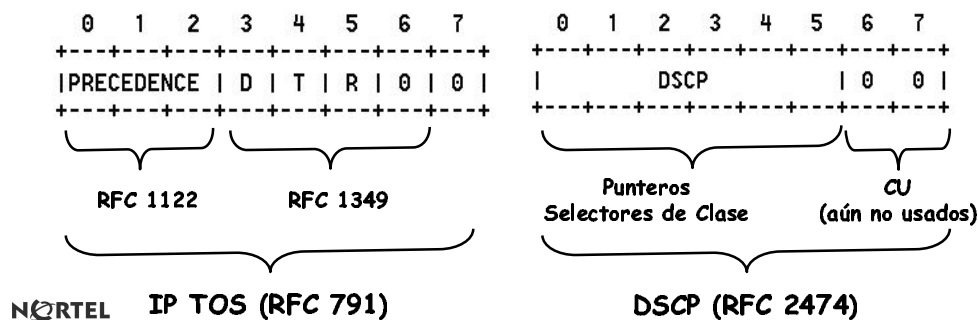
- Similar concepts to ATM
- Provides hard per-flow QoS guarantees, at the expense of complexity and reduced scalability
- Does not address QoS routing or Traffic Engineering

## Arquitectura de Servicios Diferenciados (DiffServ)



## El Campo Diferenciador de las tramas IP

- DiffServ utiliza el campo anteriormente denominado ToS (Type of Service), pero de una manera un tanto diferente ya que no preserva los valores originales de ToS según el RFC 1349.
- Los valores del DSCP permiten priorizar la trama IP.



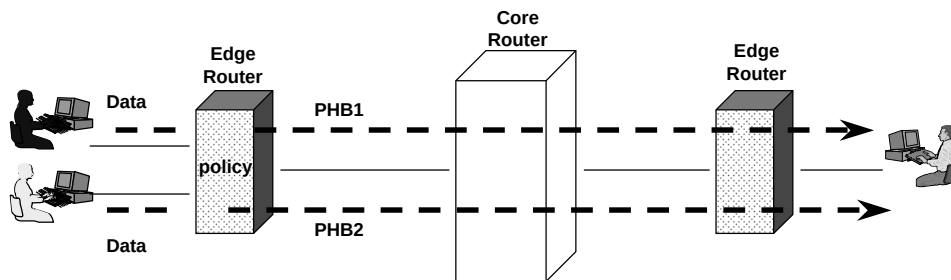
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IP TOS (RFC 791)

DSCP (RFC 2474)

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## IP QoS Mechanisms-2: Diff-Serv Architecture

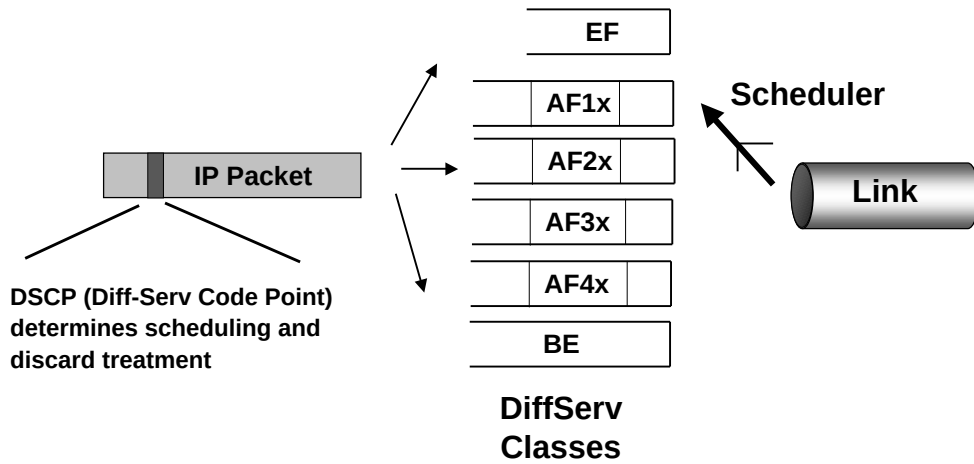


- Only Edge routers need to maintain per flow (or per aggregate) state and possibly perform policing and shaping
- Core routers need only to forward packets according to the specified PHB (Per Hop Behavior) in the DS byte
  - no per flow state, hence scalable to a large number of flows
- Provide aggregate SLAs for each traffic class (e.g. gold, silver, bronze)

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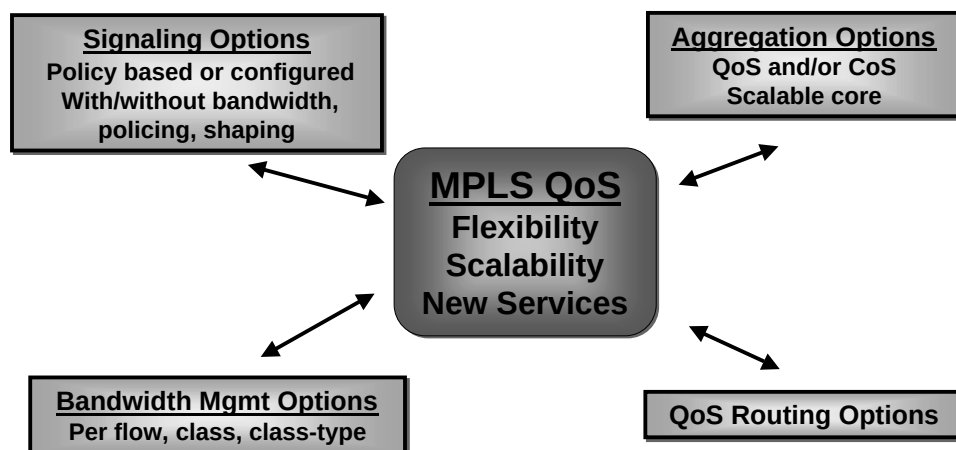
## DiffServ Forwarding



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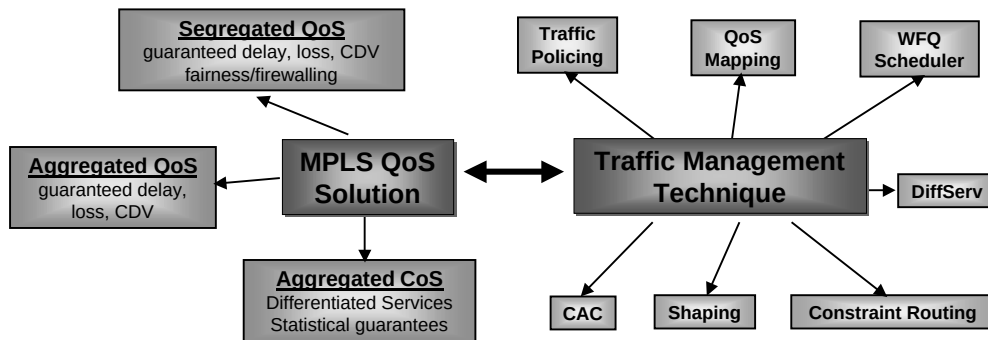
## MPLS Role for CoS/QoS Support



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## MPLS Traffic Management Techniques

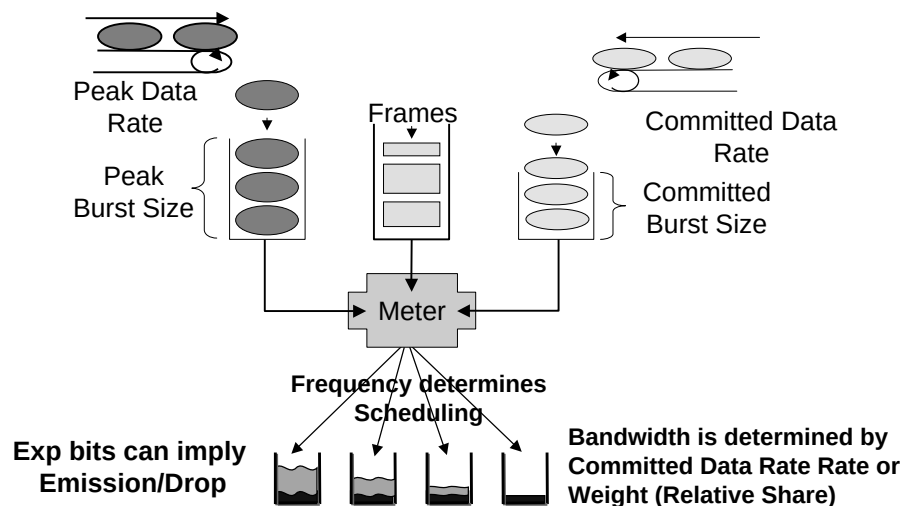


Emerging MPLS Switch/Routers Support a Rich Set of QoS Capabilities

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## Example: MPLS CR-LDP Traffic Model



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## MPLS & DiffServ: A Complementary Combination

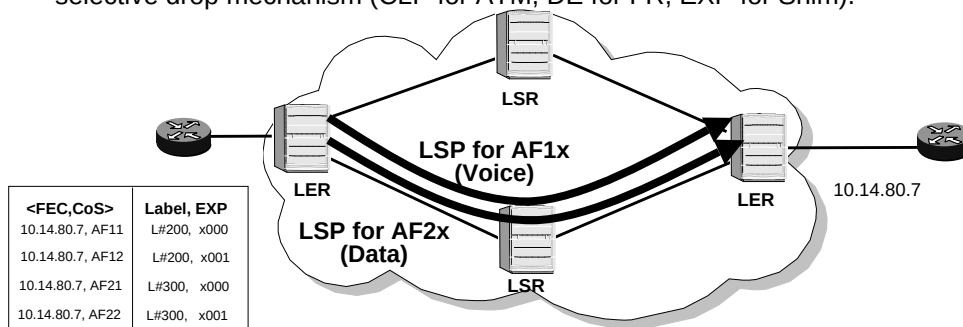
- **Both MPLS & DiffServ have same scalability goals:**
  - Aggregation of traffic on Edge
  - Processing of Aggregate only in Core
- **DiffServ can augment MPLS Signaling and Forwarding:**
  - **Signaling:** enhance LDP, CR-LDP, RSVP-TE with explicit Class-of-Service indication (e.g. EF, AF, BE)
  - **Forwarding:** DiffServ Code Points can be mapped to the MPLS label EXP Bits, to indicate individual packets discard and emission priorities
- **Two types of LSPs are defined: L-LSPs & E-LSPs**



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## Label inferred LSP (L-LSP)

L-LSPs: The scheduling treatment is inferred from the label, and the drop precedence may be inferred in the encapsulating link layer selective drop mechanism (CLP for ATM, DE for FR, EXP for Shim).



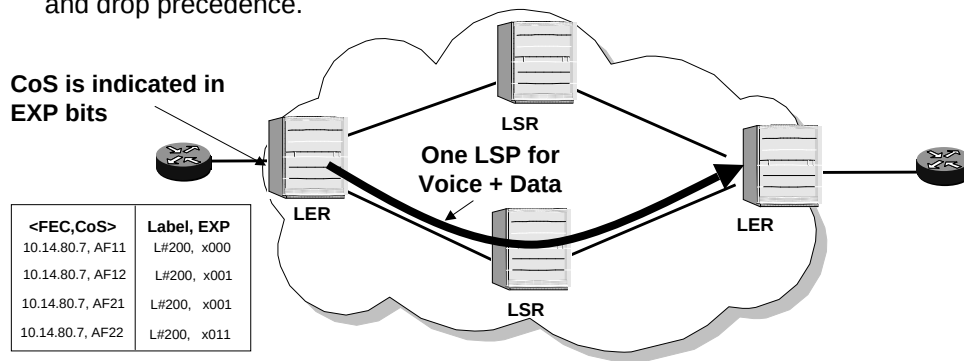
LDP/CR-LDP or RSVP establishes LSPs for each <FEC, CoS>  
Requires signaling of Diff-Serv TLV



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## EXP inferred LSPs (E-LSP)

The EXP field of the MPLS Shim header indicates the scheduling treatment and drop precedence.

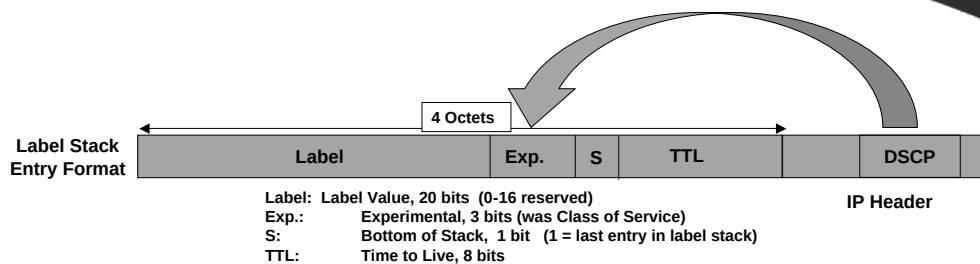


Uses LDP/CR-LDP or RSVP to establish the LSPs for each FEC  
Mapping of CoS to MPLS EXP bits is signaled or configured

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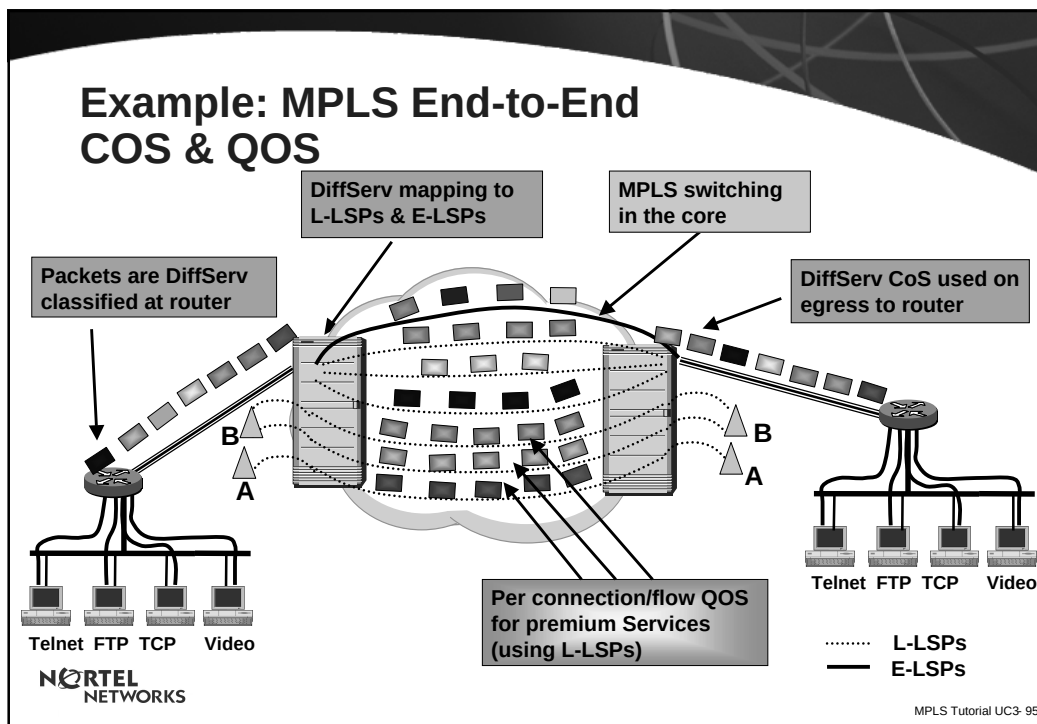
## DiffServ and E-LSP Mapping



- The 6-bit Differentiated Service Code Point (DSCP) is mapped to the 3-bit MPLS EXP Bits
- Mapping flexibility is provided through signaling or provisioning
- Allows a single LSP to support up to 8 Diff-Serv Behavior Aggregates (CoS)
- E-LSPs Cannot be supported over ATM links

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## Tutorial outline

- A little bit of History and some basic concepts
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- MPLS and QoS
- **Multi-Service over MPLS**
- MPLS and VPNs
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# Multi-Service over MPLS

- Motivation
- Architecture
- QoS Model
- ATM over MPLS Example



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- # Multi-Service over MPLS
- Motivation
  - Architecture
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- MPLS Tutorial UC3- 97

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# Architecture Concepts

The diagram illustrates the separation of Transport and Service in an MPLS network architecture. It shows two Service domains (left and right) separated by a central Transport domain.

**Service Domains:**

- Each Service domain contains a vertical dashed line representing the Service boundary.
- Inside the Service domain, there are three nodes: VR (Virtual Router), ATM (Asynchronous Transfer Mode), and FR (Frame Relay).
- The VR node is labeled with "MPLS" and "IP" above it.
- The FR node is labeled with "IGP" below it.
- The ATM node is labeled with "IGP" below it.

**Transport Domain:**

- The Transport domain is represented by a cloud labeled "MPLS core".
- Between the Service domain and the Transport domain, there is an "IWF" (Interworking Function) node.
- The IWF node is connected to the VR, ATM, and FR nodes.
- The IWF node is also connected to the "MPLS core" cloud.

**Interconnections:**

- The "MPLS core" cloud is connected to the IWF nodes on both sides.
- The IWF nodes are connected to the "IGP-TE" (Interdomain General Protocol - Traffic Engineering) node.
- The "IGP-TE" node is connected to the "Glue" node.
- The "Glue" node is connected to the "IGP" nodes on both sides.

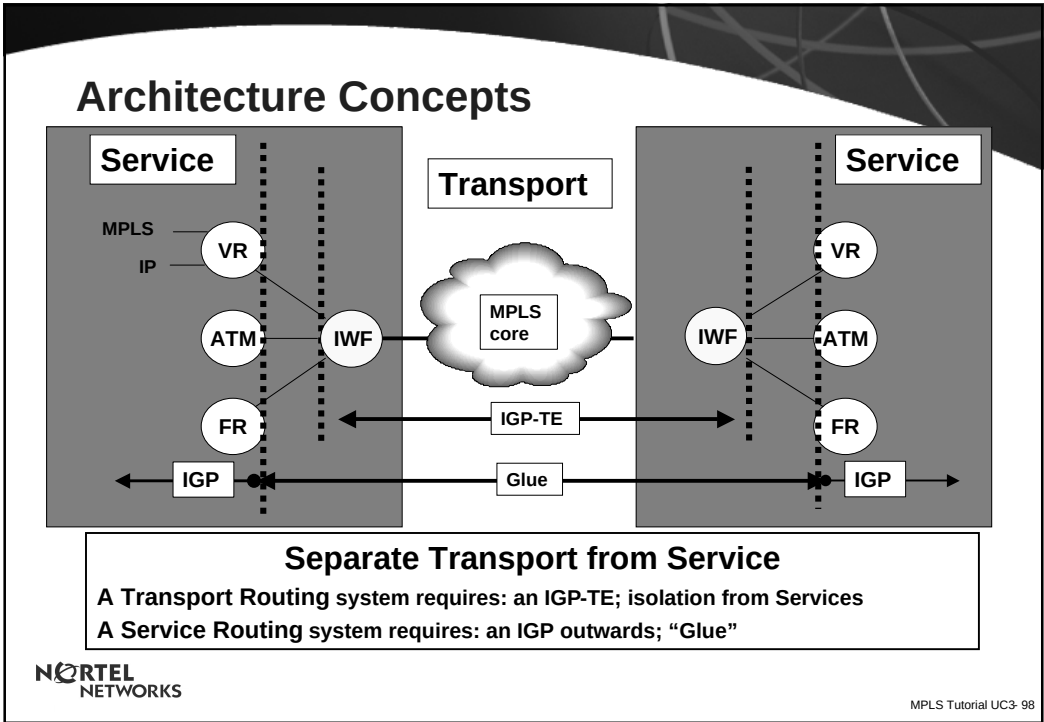
**Separate Transport from Service**

A Transport Routing system requires: an IGP-TE; isolation from Services

A Service Routing system requires: an IGP outwards; "Glue"

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**Separation and Flow:**

- The diagram shows a clear separation between the Service and Transport domains, with the Transport domain acting as a central hub.
- Arrows indicate the flow of traffic and control signals between the various components.

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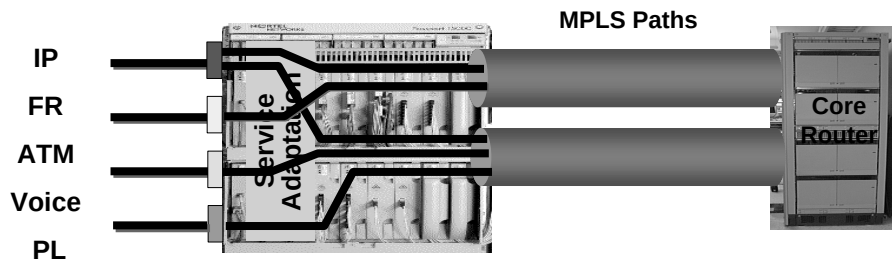
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## Multiservice Core Adaptation

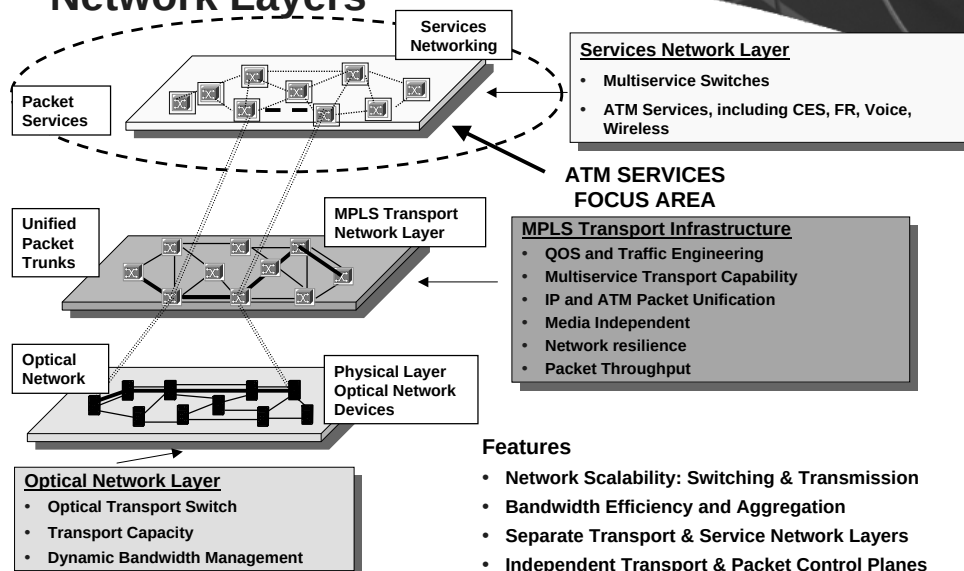


- Standard multi-service UNI and NNI capabilities
- Adaptation of existing nailed-up and switched services to MPLS/Packet Core
- Provide a range of QoS and CoS service capabilities
- Support flexible and scalable network evolution

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## Network Layers



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## Multi-Service over MPLS

### Summary

- **MPLS is the unified network core for all services**
- **MPLS enables sharing the network resources for all legacy and emerging services**
- **The architecture meets the requirements of existing services, and offers a smooth network evolution**
- **Nortel Networks is leading the drive for multi-service networking over MPLS**

## Tutorial outline

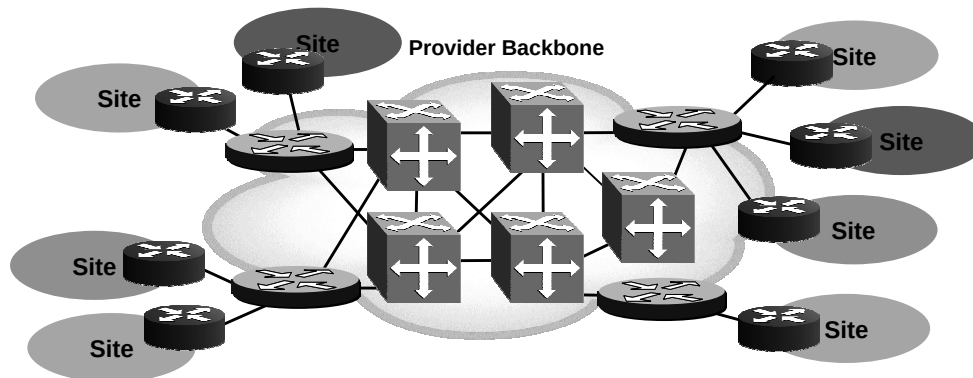
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## What is a VPN?



**VPN: Virtual Private Network**  
- a set of sites interconnected via a provider backbone

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## There are many VPN types ...

- **L2 VPNs**

- X.25 CUGS
- Frame Relay
- ATM

- **IP VPN Types (RFC 2764)**

- Virtual Leased Lines (VLL)
- Virtual Private Routed Network (VPRN)
- Virtual Private Dial Networks (VPDN)
- Virtual Private LAN Segment (VPLS)

- **Types of Tunnels**

- L2
- IP
- IPSec
- MPLS

**We are only going to discuss MPLS-based VPNs**

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## Why MPLS tunnels?

- **MPLS is an efficient tunnel technology**
- **MPLS is IP centric**
- **MPLS is L2 agnostic**
- **MPLS LSPs are connection oriented**
- **MPLS LSPs can be nested inside one another**
- **MPLS offers traffic engineering**

## MPLS VPNs still in flux

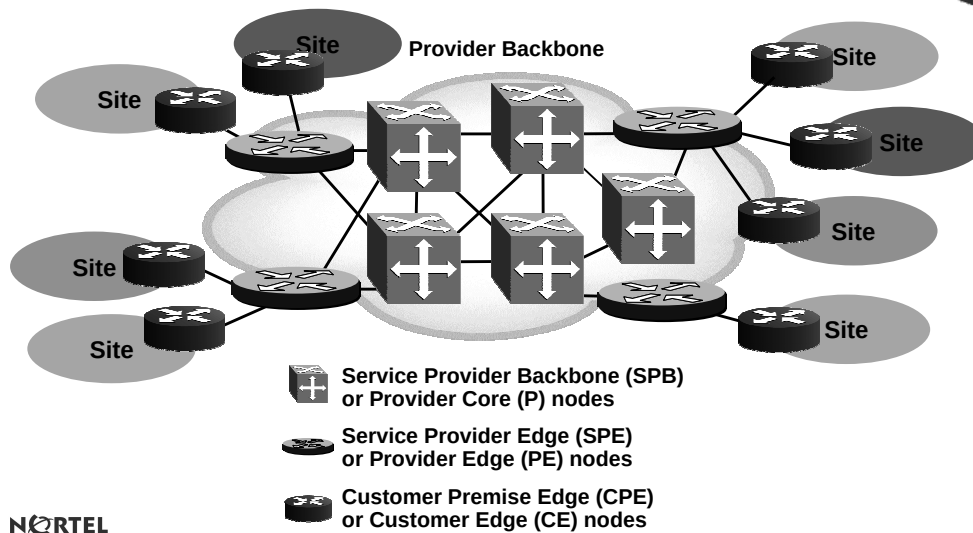
- **No agreed-to standard for MPLS-based VPNs**
- **Here we present two proposals which are being developed and deployed...**

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## Two competing sets of terms



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## Two parts to each proposal

- **Data Transport**
  - how the data packets are transported from one site to another
  - this part the same between the two proposals
- **Routing Info Distribution**
  - how routing information is transported from one site to another
  - here the two proposals differ

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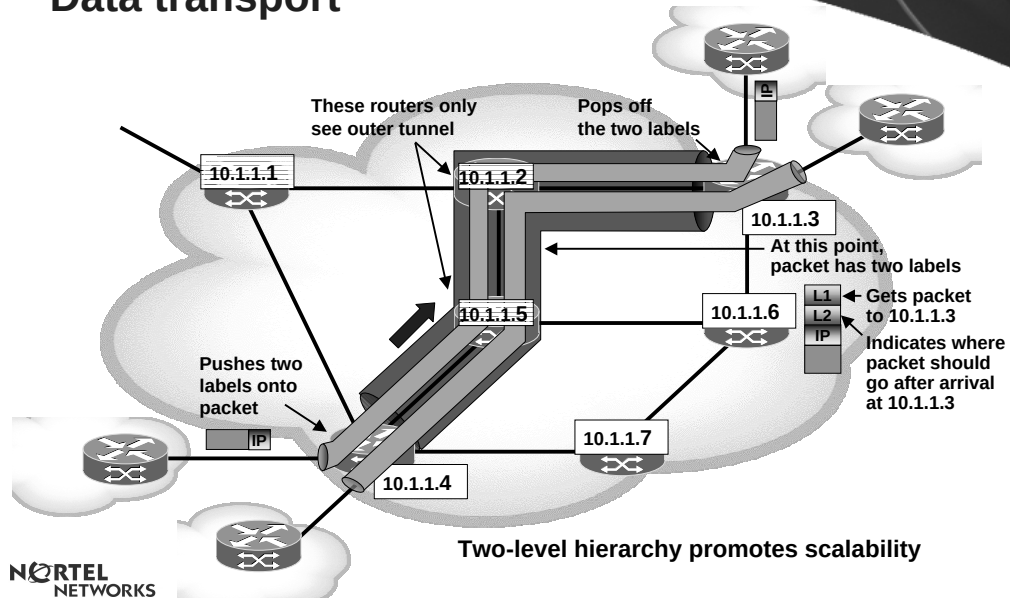
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## Data transport

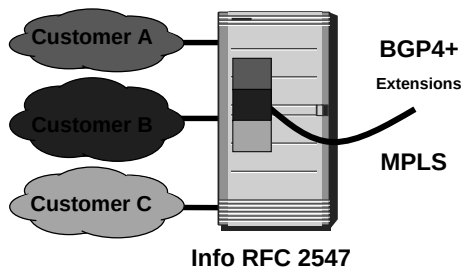


## Routing info distribution

### Method 1:

#### Multiple indexed tables in a single switch

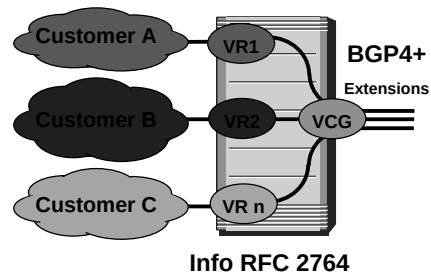
- one BGP4 process with extensions for VPNs
- standard IP routing to customer (no OSPF)
- extended BGP4 routing into the core network
- hierarchical MPLS routing required in the core network



### Method 2:

#### Virtual routers in a single switch

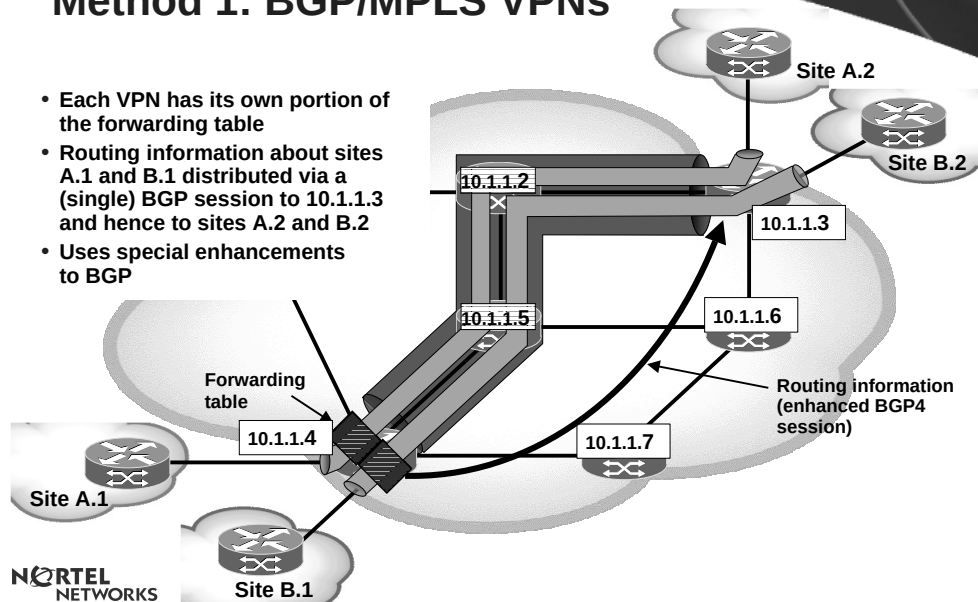
- each instance dedicated to a single customer with separate routing and forwarding tables
- standard IP routing to customer
- standard IP routing in the core network
- Core can be ATM, pure IP, or MPLS



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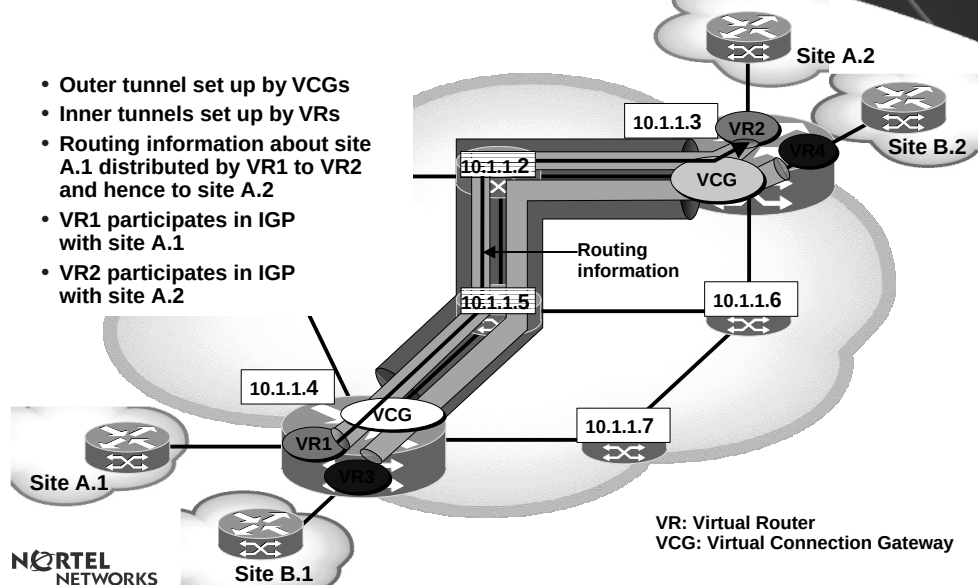
## Method 1: BGP/MPLS VPNs

- Each VPN has its own portion of the forwarding table
- Routing information about sites A.1 and B.1 distributed via a (single) BGP session to 10.1.1.3 and hence to sites A.2 and B.2
- Uses special enhancements to BGP



## Method 2: Virtual Router VPNs

- Outer tunnel set up by VCGs
- Inner tunnels set up by VRs
- Routing information about site A.1 distributed by VR1 to VR2 and hence to site A.2
- VR1 participates in IGP with site A.1
- VR2 participates in IGP with site A.2



## What protocol should we use?

### LDP?

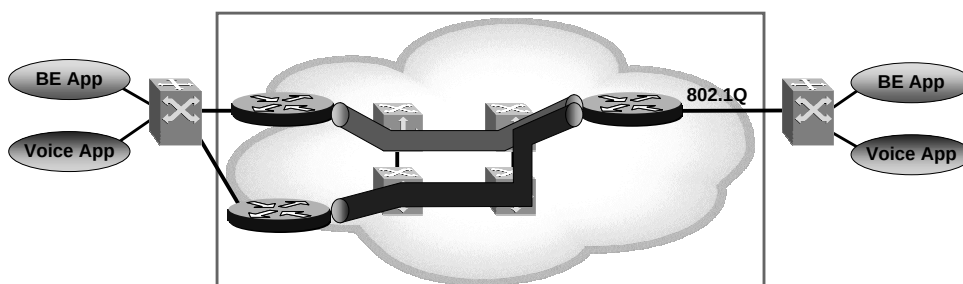
- Automatic tunnel setup
- Merging LSPs  
→ more scalable
- No traffic engineering or QoS

### CR-LDP / RSVP-TE?

- Configured tunnel setup
- Point-to-point LSPs  
→ less scalable
- Provides traffic engineering and QoS

Could use a combination

## Example of CoS in a VPN



- The Best Effort traffic (blue) and the voice traffic (red) take divergent paths on the network
- The red path is optimized through traffic engineering for low latency applications

## Tutorial outline

- A little bit of History and some basic concepts
- Applications Overview
- Data Plane
- Control Plane
- MPLS and QoS
- Multi-Service over MPLS
- MPLS and VPNs
- **MPLS and ASON**
- Summary and some MPLS sources of information

## Smart Optical Layer Evolution

Evolving from Static Connectivity to a Dynamic Infrastructure and Service Layer

More Agile

What do we need to make it “Smart”?

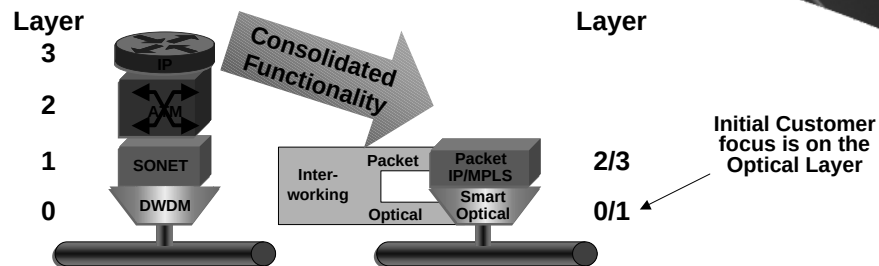
- Agile Optical Layer
- Automatic Switched Optical Network (ASON)

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## Smart Packet/Optical Interworking



### Drivers

- Traffic Growth
- Multi-Service
- Simplicity
- Service Velocity
- Network Cost

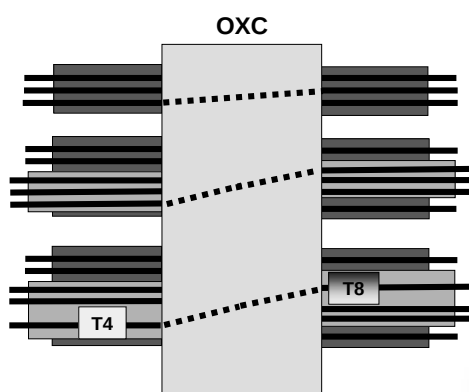
### Challenges

- Robustness and Support for QoS
- Policy Based Networking
- Bandwidth Management Optimization
- Flexible Restoration

**NORTEL**  
NETWORKS

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## Optical cross-connect switch



### • Can cross-connect:

- fiber-to-fiber
- wavelength-to-wavelength
- timeslot-to-timeslot

**NORTEL**  
NETWORKS

## Treat these as labels

- **Using MPLS, we can think of each of these as a label**
  - Fiber number N in the bundle (N is the label)
  - Wavelength  $\lambda$  on the fiber ( $\lambda$  is the label)
  - Timeslot T on the fiber (T is the label)
- **Changing N,  $\lambda$ , or T going through an optical switch is thus a label swap**
- **Can use CR-LDP / RSVP-TE to set up the cross-connects**

## Tutorial outline

- A little bit of History and some basic concepts
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- MPLS and ASON
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## Important Features of MPLS

- **Runs over many different Layer 2 technologies**
  - Ethernet, PoS, ATM, FR, Optical
- **Most probably will be only IP (MPLS ->IPLS)**
- **LSPs can be point-to-point or merging**
  - Point-to-point LSPs allow explicit routing and QoS reservations
  - Merging LSPs reduce number of LSPs required
- **LSPs can nest inside other LSPs**
  - Provides scalability; core routers know only about outermost LSP

## Setting up LSPs

- **LDP**
  - Merging LSPs that follow the shortest path
  - No QoS
- **CR-LDP or RSVP-TE**
  - Point-to-point LSPs
  - Explicit route, QoS reservations, Preemption, Make-before-Break
- **Constraint Based Routing (eg. OSPF or ISIS)**
  - Can enhance with TE extensions to do online path selection

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## Important Applications of MPLS

- **Traffic Engineering**
  - Use point-to-point LSPs to move traffic away from congested links onto under-utilized links.
- **Replace BGP on interior routers**
  - Use mesh of LSPs to avoid the need to run BGP on interior routers.
- **Integrate IP and ATM**
  - Use MPLS to set up merging LSPs through ATM switches, thus avoiding  $N^2$  and  $N^3$  problems.
- **Virtual Private Networks**
  - Use LSPs as tunnels to provide private connections through a public network
- **Automatically Switched Optical Networks**
  - Use MPLS signaling rather than manual configuration to set up cross-connects inside optical switches.



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## MPLS Resources

- **Nortel's MPLS website**
  - <http://www.nortelnetworks.com/mpls>
  - Contains white papers, product information, and freely-available source code
- **MPLS Resource Center**
  - <http://www.mplsrc.com/>
  - A commercial web site offering MPLS information.  
Good place to look for books, articles, press releases, etc.



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## MPLS Resources

- **MPLS Working Group at the IETF**
  - <http://www.ietf.org/html.charters/mpls-charter.html>
  - This is group that does all the work on MPLS. Anyone can subscribe to the mailing list and read the documents.
- **MPLS WG mailing list archive**
  - <http://cell.onecall.net/cell-relay/archives/mpls/mpls.index.html>
  - Here you can read earlier discussions on the mailing list.
- **Archive of internet-drafts related to MPLS**
  - <http://infonet.aist-nara.ac.jp/member/nori-d/mlr/>
  - Internet-drafts are deleted from the IETF site after 6 months or when a new version comes out. Here you can find the old versions, as well as other older goodies.
- **Free Linux implementation: University of Wisconsin**
  - <ftp://nero.doit.wisc.edu/pub/mpls/>



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## MPLS WG Documents

- **The MPLS Working Group has created lots of documents. Here are some good ones to start with.**
  - “Multiprotocol Label Switching Architecture”
    - Gives complete and precise definitions of basic MPLS concepts. Good document to read first..
  - “MPLS Label Stack Encodings”
    - Describes the format of the MPLS label stack. Note that for some formats (e.g., ATM and FR), this information needs to be supplemented with other documents.
  - “LDP Specification”
    - The protocol specification for LDP.
  - “Constraint-Based LSP Setup using LDP”
    - The protocol specification for CR-LDP.
  - “RSVP-TE: Extensions to RSVP for LSP Tunnels”
    - The protocol specification for RSVP-TE.
- **These documents are available on the MPLS WG web page under “Internet Drafts” and “Request for Comments”.**



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## MPLS Standards Update

- **LDP/CR-LDP RFCs coming soon**
  - <http://www.ietf.org/internet-drafts/draft-ietf-mpls-ldp-10.txt>
  - <http://www.ietf.org/internet-drafts/draft-ietf-mpls-cr-ldp-04.txt>
- **CR-LDP Modify -- Informational RFC**
  - <http://www.ietf.org/internet-drafts/draft-ietf-mpls-crlsp-modify-01.txt>
- **CR-LDP Feedback -- past WG last call**
  - <http://www.ietf.org/internet-drafts/draft-ietf-mpls-te-feed-01.txt>
- **MPLS LDP Query**
  - <http://www.ietf.org/internet-drafts/draft-paraschiv-mpls-lsp-query-00.txt>
- **Extensions for support of Differentiated Services Traffic Engineering**
  - <http://www.ietf.org/internet-drafts/draft-lefaucheur-diff-te-ext-00.txt>
- **COPS Usage for MPLS/Traffic Engineering**
  - <http://www.ietf.org/internet-drafts/draft-franr-mpls-cops-00.txt>



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## MPLS Standards Update

- **Network based IP VPN Architecture Using Virtual Routers**
  - <http://www.ietf.org/internet-drafts/draft-ouldbrahim-vpn-vr-01.txt>
- **BGP/VPN: VPN Information Discovery for Network-based VPNs**
  - <http://www.ietf.org/internet-drafts/draft-ouldbrahim-bgp-vpn-00.txt>
- **Framework for MPLS Based Recovery**
- **Fault Tolerance for LDP and CR-LDP**
- **FLIP: draft-sandiick-flip-00.txt**
- **Extensions to CR-LDP and RSVP-TE for setup of pre-established recovery tunnels**
  - <http://www.ietf.org/internet-drafts/draft-hellstrand-mpls-recovery-merge-00.txt>



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## MPLS Standards Update

- **IP over Optical Networks: A Framework**
- **MPLS Optical/Switching Signaling**
  - <http://www.ietf.org/internet-drafts/draft-ashwood-generalized-mpls-signaling-00.txt>
- **OSPF Extensions in Support of MPL(ambda)S**
  - <http://www.ietf.org/internet-drafts/draft-kompella-ospf-ompls-extensions-00.txt>
- **IS-IS Extensions in Support of MPL(ambda)S**
  - <http://www.ietf.org/internet-drafts/draft-kompella-isis-ompls-extensions-00.txt>
- **A User-Network Interface (UNI) for re-Configurable Optical Networks**
  - <http://www.ietf.org/internet-drafts/draft-aboulmagd-mpls-ldp-optical-uni-00.txt>

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