MPLS LSP ESTABLISHMENT FOR DIFFERENTIATED SERVICE AND INTEROPERABILITY ISSUES WITH ATM-PNNI NETWORKS

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PREFACE

This Thesis addresses the interfacing issues of ATM PNNI with MPLS to provide the Differentiated Service.

MPLS (Multi Protocol Label Switching) Network is such a multiple layer switching technology, that it uses the QoS properties of ATM, supports multiple protocols and can be implemented on several platforms. MPLS is a very good standard for improving the performance, reliability and scalability of IP networks by engineering deterministic route selection and providing a mechanism for traffic management.

Private Network-to-Network Interface is a dynamic routing protocol for ATM that allows for the exchange of routing information with the help of topology state packet between ATM switches. It allows switches in a network to determine the best route to establish a connection. It allows for a greater scaling of ATM enterprises and automates the routing table process.

The purpose of this study was to find a solution for LSP establishment for Differentiated Service in MPLS domain and interoperating ATM PNNI networks with the newly developing Multi protocol Label Switching (MPLS) networks. The Exact details of MPLS LSR operation to support the QoS. In addition, packet travel from MPLS domain to ATM-PNNI domain with proper conversion and encoding of Differentiated

Service and Traffic Engineering information unit is proposed. ATM PNNI-MPLS networks with QoS support can provide the aspect of reliability, scalability, flexibility, utilization efficiency and backward compatibility.

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NOMENCLATURE

AF	Assured Forwarding
BA	Behavior Aggregate
BGP	Border Gateway Protocol
CLP	Cell Loss Priority
CoS	Class of Service
CS	Class Selector
DE	Discard Eligibility
DF	Default Forwarding
Diff-Serv	Differentiated Service
DSCP	Differentiated Services Code Point
EF	Expedited Forwarding
E-LSP	EXP-Inferred-PSC LSP
EXP	EXPerimental (bits)
FEC	Forwarding Equivalency Class
FTN	FEC-To-NHLFE Map
ILM	Incoming Label Map
LC-ATM	Label Switching Controlled-ATM (interface)
L-LSP	Label-Only-Inferred-PSC LSP
LSP	Label Switched Path
LSR	Label Switch Router
MPLS	Multi-Protocol Label Switching
NHLFE	Next Hop Label Forwarding Entry
OA	Ordered Aggregate. The set of Behavior Aggregates, which share an ordering level.
OSPF	Open Shortest Path First Protocol
PHB	Per Hop Behavior

PNNI	Private Network to Network Interface.
PSC	PHB Scheduling Class. The set of one or more PHB(s) that are applied to the constraint. Behavior Aggregate(s) belonging to a given OA. For example, AF1x is a PSC comprising a single PHB, the EF PHB. comprising the AF11, AF12 and AF13 PHBs. EF is an example of PSC
PVC	Permanent Virtual circuit.
PVP	Permanent Virtual Path.
QoS	Quality of Service
RIP	Routing Internet Protocol
RTCP	Real Time Control Protocol
RTP	Real Time Protocol
SNMP	Simple Network Management Protocol
SVC	Switched Virtual Circuits
TE	Traffic Engineering
TLV	Type Length Value
UNI	User Network Interface.
VCI	Virtual circuit Identifier
VPI	Virtual Path Identifier
VPN	Virtual Private Network

CHAPTER I

INTRODUCTION

This chapter talks about the general introduction about the Quality of Service (QoS), types of QoS. The chapter also describes general description of Multi-Protocol Label Switching (MPLS), MPLS Features, and MPLS benefits over ATM or ATM-PNNI networks.

1.1 Quality of Service

Quality of Service (QoS) is the guarantee to the network connection that, within some limit, the required or requested service levels for traffic would be available. To assure the QoS, it is a must condition that all the network layers from Application Layer to Physical Layer should cooperate with the same level of Peers i.e. Host or Router's Layers. QoS may also be called as Class of Service (CoS). Service Level Agreement (SLAs) is used to specify the QoS [9].

There are mainly two types of QoS:

(1) Resource Reservation (Integrated Services (Int-Serv)): Network Resources are allotted to serve the desired application depending on QoS request, which also include the Bandwidth management policy.

Resource Reservation Protocol is used to provide Int-Serv.

(2) Prioritization (Differentiated Service (Diff-Serv)): Network Traffic is categorized and apportioned network resource according to Class of the Traffic depending on the Bandwidth request. By providing this classifications service to the network application, we can enable these most demanding QoS requirements. Diff-Serv is the most challenging service in demand today.

1.2 MPLS: (Multiprotocol Label Switching)

Multi-Protocol Label Switching (MPLS) is very effective method to forward the packets (frames or cells) from source to destination. When packet enters the MPLS domain, the edge ingress Label Switch Router (LSR) applies a 20 bits label to the packets. These packets pass through different core LSRs and ATM (Asynchronous Transmission Mode) switches in the network with minimum overhead of 20 bits lookup label.

MPLS combines high performance and different traffic parameters of Data Link Layer with the features of Network Layer like scalable routing. Since this method is applicable to any of the Layer 3(Network Layer) protocol, we call it "Multiprotocol". It also provides flexible IP (Internet Protocol) routing over ATM switching of Layer 2.

The basic job of the router in any connectionless network protocol is to decide independently for each packet, 'where to forward the packet'. Based on the analyzed information of the packet header and routing algorithm of the router, it decides next hop. This packet header has more information than is required to forward to the next hop. First router will find out what are the traffic engineering parameters required for the packets and depending on it, router will assign the Forwarding Equivalence Classes (FECs) of the packet. Now different packets, which belong to same FEC, travel along the same path. In network layer protocol, each router will check the packets and reassign the FEC. With this FEC information and routing table lookup, it will determine the next hop.

To get rid of the complex header analysis of packets at each hop, MPLS attach a fixed length labels. When the new packet enters the MPLS domain, ingress LSR will examine layer 3 header of the packet and assign the FEC once. Now the packets or cells have these short labels to make the decision at each hop where to forward. This label has summary information of destination, Virtual Private Network (VPN) membership, Class of Service (CoS) or Quality of Service (QoS) and complete map of the route depending on the traffic parameters. All the core routers need this label to examine the incoming packets. Core routers, depending on the next hop information in the label, perform POP, PUSH or SWAP operations. At the other end of the MPLS network, the Edge LSR swaps (remove the old label and apply new label if needed) the label and apply proper header data link label.

The main goal of the providing this new forwarding method is to use a unique lookup table from a fixed-length label depending on the information of the source and destination. By using label-switching technique, we can combine the switching function of data link layer and routing function of the network layer. Forwarding decision method makes it feasible for switches and routers to integrate the reachability information of the layer 3 with traffic engineering parameters of layer 2 [2].

1.3 MPLS Features:

(i) MPLS integrates routing protocols (OSPF, RIP or IS-IS) with scalable IP routing within an ATM Backbone.

(ii) MPLS supports for Border Gateway Protocol (BGP). MPLS also provide connectionless, private delivery of IP QoS. That is called as IP Virtual Private Network Services (VPN).

(iii) To support the VPN with Differentiated Services, MPLS supports the Service-Level Agreements (SLA).

1.4 MPLS Benefits

By looking at the features of MPLS the first question comes in the mind is " Why MPLS?" This section talks about the advantages of MPLS networks over ATM/ATM-PNNI networks.

MPLS offers many advantages over Traditional IP over ATM.

1) Integration:

   MPLS is advantageous when works with existing ATM infrastructure. MPLS integrates IP routing capability with ATM functionality rather than using IP over ATM. MPLS doesn't require ATM addressing and routing techniques.

2) Higher Reliability:

   When applied to ATM infrastructure especially with Wide Area Networks MPLS is permanent, easy and one time solution for combing routing protocols with Layer 2 equipment ATM switches. In existing ATM under IP technique, one can set up Permanent Virtual Circuits in between the routers over ATM domain. Within the ATM domain, one can use the Next Hop Resolution Protocol (NHRP) to establish the Switched Virtual Circuits (SVCs). There are lots of problems in this approach, one of them is if one ATM link fails, it makes several router-to-router links failure. That makes more processing due to large amount of traffic through the routers.

3) Better Efficiency:

In traditional IP routing all the traffic find same route as cheap route. It mislead to inefficient routing in ATM domain. To eliminate hotspot we need to do extensive tuning of routing weights, which is costly.

4) Direct Classes of Service Implementation:

MPLS uses ATM queuing and buffer capabilities. To provide different Service Level Agreements, with those SLAs it defines Classes of services for ATM hardware. MPLS uses those entire CoS with direct support of IP precedence, which is defined in ATM Forum, without complex modifications.

5) More Elegant support of Multicast and RSVP:

In contrast of overlaying ATM under IP hardware, MPLS has other advantage like IP multicast. MPLS also support for RSVP. More research is required for these standards and implementations.

6) Virtual Private Network Scalability and Manageability:

IP Virtual Private Network (VPN) means Private IP networks within any enterprise. MPLS domain makes VPN services extremely scalable and easily manageable. Each network can have hundreds of VPNs. With the best support of

MPLS, VPN information can be processed only at the ingress and egress nodes. One can use Border Gateway Protocol (BGP) with MPLS to provide VPN services like VPN sites and VPN membership. MPLS Labels led the packet to their correct egress node.

7) Reduces Load on Network Cores (More Robust):

   With the Hierarchical Routing knowledge of MPLS, one can access the Internet routing table. One can eliminate or reduce the transit traffic entering to Autonomous System with the help of this routing table. With MPLS, one can apply Label to the packets such that it can associate with specific exit node. By doing so, we can reduce processing in our transit routers or switches. By proper separation of Internet traffic one can improve robustness and stability.

8) Traffic Engineering Capabilities:

   MPLS supports different traffic engineering parameters like traffic type, time jitter, time delay, traffic load, destination etc. By using these parameters one can divide the traffic from over-loaded route to under-loaded to eliminate the Hotspot. MPLS enables us to utilize the network resources efficiently.

Summary:

In this chapter, we have defined terms like QoS, Diff-Serv and Int-Serv, which will show us the significance of the thesis. The difference between these terms is to know the demand of parameters depending on the service type.

MPLS introduction will help us to build the basic foundation for MPLS LSP establishment. MPLS features and benefits tell us about the superiority of MPLS Vs ATM-PNNI networks.

CHAPTER II

LITERATURE REVIEW

This section contains the introductory information about MPLS architecture, MPLS key components like Label Switch Router (LSR) and Label Switch. It also provide over view of Label Distribution Protocol and Label Switch Path.

2.1 MPLS Architecture:

A typical structure for Multiprotocol Label Switching networks used by providers (carriers or ISPs) is shown in Figure 2.1.

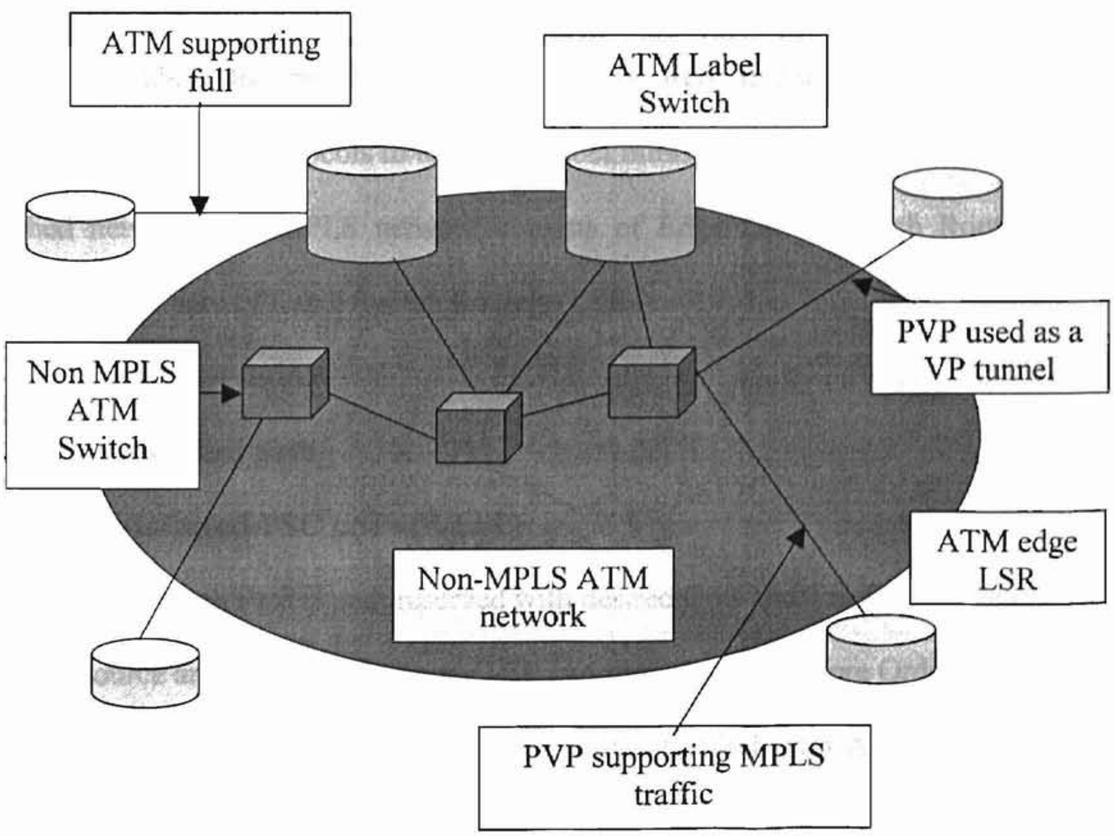

Figure 2-1 MPLS Architecture.

The basic elements in a label-switching network are:

2.1.1 Edge Label Switch Routers

Edge Label Switch Routers can be found at the boundaries of a MPLS network. As mentioned above they provide Layer 3 services and attach a label to the packet depending on the destination. They can be either routers or LAN switches.

2.1.2 Label Switches

Label switches forward the packets based on the labels. They might also provide the full support for Network Layer Routing or Data Link Layer switching to the packets.

2.2 Label Distribution Protocol

The Label Distribution Protocol (LDP) is used in conjunction with standard network layer routing protocols to distribute label information between devices in a label switched network. An MPLS network consists of Edge Label Switch Routers (Edge LSRs) around a core of Label Switch Routers (LSRs).

2.2.1 Label Switched path

2.2.1.1 EXP-Inferred-PSC LSPs (E-LSP)

Label Switch Path is path reserved with desired QoS and Traffic parameters between Source and Destination. Single LSP can support one or more Ordered Aggregate (OA). Service Level Agreements can be defined by set of Behavior Aggregates (BA). Those BAs can have different ordering level. That is OA. A single LSP can support one or more OAs. Each BA can have any number of OAs. Such LSP supports 8 BAs for a particular FEC. LSR uses EXP field of MPLS shim Header for such LSP to decide the Per Hop Behavior (PHB) to forward the given packet. This includes both the PHB Scheduling Class (PSC) and the drop preference [10].

Since the PSC for the given traffic on this LSP depends on EXP value in the MPLS header, we call this LSP as "EXP-inferred-PSC LSP" (E-LSP).

To decide the proper PSC and drop precedence for packet E-LSP uses the mapping from EXP field to PHB. The mapping of EXP→PHB can be signaled at Label set-up request or predefined mapping is used in the LSR.

Label contains the information about the combination of FEC and the set of BAs (i.e. OAs) in the E-LSP. E-LSP supports all the BAs defined in the label. Label itself represents the complete FEC.

To support the Diff-Serv in MPLS domain, all the pre-configured E-LSPs can support and transport the whole set of eight or less BAs. For a given FEC, two given E-LSPs using signaled EXP←→PHB mapping can support the same or different sets of Ordered Aggregates.

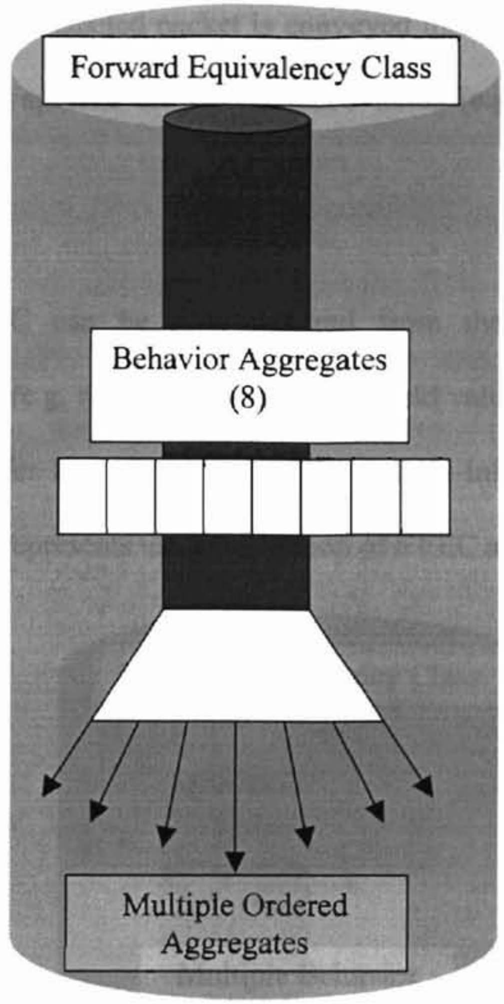

Figure 2-2 EXP- Inferred-PSC LSP (E-LSP).

2.2.1.2 Label-Only-Inferred-PSC LSPs (L-LSP)

For forwarding packets, for each pair of <FEC, OA> we can have different separate LSP.

PSC is signaled explicitly at Label establishment time for such LSP. So that later on LSR can infer PSC from Label value to forward the labeled packet. In the case of E-LSP shim header of MPLS is used to define the Drop Precedence using the EXP field. When the shim header is not used (e.g. MPLS Over ATM), the Drop Precedence to be applied by the LSR to the labeled packet is conveyed inside the encapsulated link layer header using link layer specific drop precedence fields (e.g. ATM Cell loose Priority (CLP)) [10].

Since the PSC can be fully inferred from the label without any other information at the LSR (e.g. regardless of the EXP field value as explained above in the case of E-LSP), we refer to such LSPs as "Label-Only-Inferred-PSC LSPs" (L-LSP). With L-LSPs, the label represents the combination of a FEC and an OA.

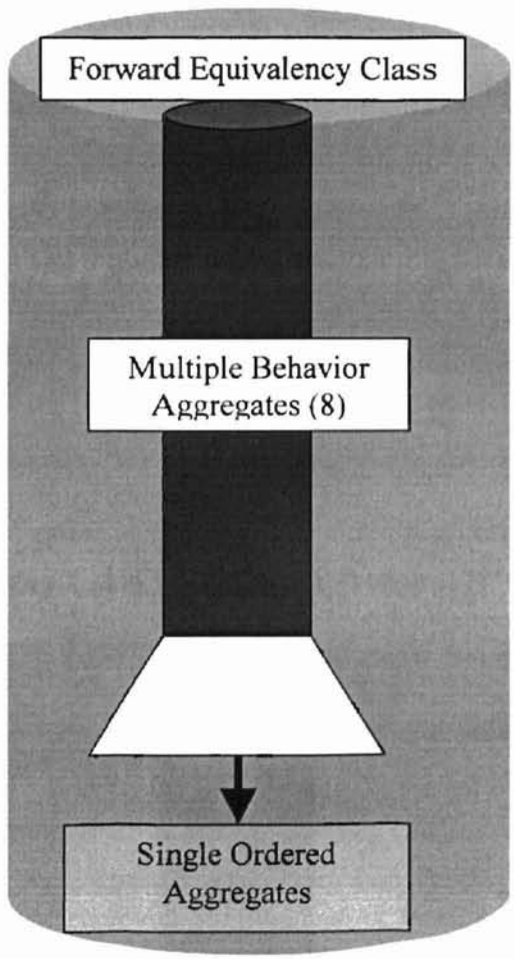

Figure 2-3 Label-Only-Inferred-PSC LSPs (L-LSP).

In this chapter we have talked about the key component of MPLS, which will be used throughout the paper. LSP is the path between ingress router and egress router to forward the packet. We will use these E-LSP and L-LSP in chapter III and chapter V to define the function of MPLS LSR. In chapter V, we will use both of these LSPs to describe the packet travel from MPLS domain to ATM-PNNI domain as well as vice-versa.

CHAPTER III

LITERATURE REVIEW

This chapter provides basic overview for signaling protocol for MPLS architecture. It talks about different messages and message format. These messages can be used in chapter V for discussing the details to support Diff-Serv. In this chapter, the detail specification of protocol is also provided. For that different <Time, Length, Values> are also presented.

In this chapter the basic Diff-Serv LSR's operation is also be discussed. LSR has to perform different procedure to forward the Label or packet. The basic steps for that procedure are described. In last topic of the chapter the exact operation of LSR has been discussed.

3.1 Constraint-Based Routing Label Distribution Protocol (CR-LDP)

As mentioned in [2], LDP is a number of steps through it one LSR informs other LSR, how and where to forward the traffic through and between them [11].

The MPLS architecture doesn't apply only one label distribution protocol. In fact, a number of different label distribution protocols are being combined to accomplish the MPLS architecture. Existing protocols have been modified slightly so that label distribution can be piggybacked on them. Like Extension to Resource Reservation

Protocol (E-RSVP) and Constraint based Label distribution Protocol (CR-LDP). Several new protocols have also been defined for the explicit purpose of defining and distributing labels in between the LSRs.

The Label Distribution Protocol (LDP) is a new protocol defined for distributing labels. It is the set of procedures and messages by which Label Switched Routers (LSRs) establish Label Switched Paths (LSPs) through a network by mapping network-layer routing information directly to data-link layer switched paths. These LSPs may have an endpoint at a directly attached neighbor (comparable to IP hop-by-hop forwarding), or may have an endpoint at a network egress node, enabling switching via all intermediary nodes.

LDP associates a Forwarding Equivalence Class (FEC) [2] with each LSP it creates. The FEC associated with an LSP specifies which packets are "mapped" to that LSP. LSPs are extended through a network as each LSR "splices" incoming labels for a FEC to the outgoing label assigned to the next hop for the given FEC. More information about the applicability of LDP can be found in [1, 15].

3.1.1 Constraint-Based LSP Setup using LDP

Label Distribution Protocol (LDP) is defined in [1] for distribution of labels inside one MPLS domain. One of the most important services that may be offered using MPLS in general and LDP in particular is support for constraint-based routing of traffic across the routed network. Constraint-based routing offers the opportunity to extend the information used to setup paths beyond what is available for the routing protocol. For instance, an LSP can be setup based on explicit route constraints, QoS constraints, and other constraints. Constraint-based routing (CR) is a mechanism used to meet Traffic Engineering requirements that have been proposed by [2] & [3]. These requirements may be met by extending LDP for support of constraint-based routed label switched paths (CR-LSPs).

3.1.2 Constraint-based Routing Overview

The main purpose of imposing the Constraint on the routing is to support the Traffic Engineering (TE) Requirements. Explicit Routing is one of the Constraint-based routing, where we defined our Explicit Route (ER) as the constraint. Other Constraints are used to provide privileges to the Network Operator to control the path govern by the LSP [11].

CR-LSP is also the path through the MPLS domain to forward the traffic. The simple LSP can be setup based on the routing information in the Routing table or from a management system, while the CR-LSP setup at the boundary of the MPLS domain based on the requirement as well as the routing information. This additional functionality helps CR-LSP to provide the better service for TE. By using the CR-LSP one can reserve certain amount of Bandwidth or provide special Service Class to the LSP, or to share the load between alternative routes through the MPLS domain to utilize the separate physical paths. CRLDP is used to support Pre-emption, Route Pinning, Resource Class and Strict and Loose Explicit Routes.

Preemption

CR-LDP signals the resources required by a path on each hop of the route. If a route with sufficient resources cannot be found, existing paths may be rerouted to reallocate resources to the new path. This is the process of path pre-emption. Setup and holding priorities are used to rank existing paths (holding priority) and the new path (setup priority) to determine if the new path can pre-empt an existing path.

The setup priority of a new CR-LSP and the holding priority attributes of the existing CR-LSP are used to specify priorities. Signaling a higher holding priority express that the path, once it has been established, should have a lower chance of being pre-empted.

Signaling a higher setup priority expresses the expectation that, in the case those resources are unavailable, the path is more likely to pre-empt other paths. The exact rules determining bumping are an aspect of network policy. The allocation of setup and holding priority values to paths is an aspect of network policy.

The setup and holding priority values varied from zero (0) to seven (7). The value zero (0) is the priority assigned to the most important path. It is referred to as the highest priority. Seven (7) is the priority for the least important path. The use of default priority values is an aspect of network policy. The recommended default value is (4).
The setup priority of a CR-LSP should not be higher (numerically less) than its holding priority since it might bump an LSP and be bumped by the next "equivalent" request.

3.2 Solution Overview

CR-LSP over LDP Specification is designed with the following goals:

1. Meet the requirements for performing traffic engineering and provide a solid foundation for performing more general constraint-based routing.
2. Build on already specified functionality that meets the requirements whenever possible. Hence, this specification is based on [1].
3. Keep the solution simple.

3.2.1 Label Request Message

An LSR sends the Label Request Message to an LDP peer to request a binding (mapping) for a FEC. The Label Request Message must include a single FEC-TLV & LSPID TLV element [1, 17].

The encoding for the CR-LDP Label Request Message is as follows:

Table 3-1 Label Request Message.

<table>
<tr><td>0</td><td>Label Request (0x0401)
(15 bits)</td><td>Message Length
(16 bits)</td></tr>
<tr><td colspan="3">Message ID</td></tr>
<tr><td colspan="3">FEC TLV</td></tr>
<tr><td colspan="3">LSPID TLV (CR-LDP, mandatory)</td></tr>
<tr><td colspan="3">ER-TLV (CR-LDP, optional)</td></tr>
<tr><td colspan="3">Traffic TLV (CR-LDP, optional)</td></tr>
<tr><td colspan="3">Pinning TLV (CR-LDP, optional)</td></tr>
<tr><td colspan="3">Resource Class TLV (CR-LDP, optional)</td></tr>
<tr><td colspan="3">Pre-emption TLV (CR-LDP, optional)</td></tr>
<tr><td colspan="3">Diff-Serv TLV (CR-LDP, optional)</td></tr>
</table>

3.2.2 Label Mapping Message

An LSR sends a Label Mapping message to an LDP peer to advertise FEC-label bindings to the peer. The Label Mapping Message must include a single Label-TLV [17].

A Mapping message is transmitted by a downstream LSR to an upstream LSR under one of the following conditions:

1. The LSR is at the egress end of the CR-LSP and an upstream mapping has been requested.
2. The LSR received a mapping from its downstream next hop LSR for a CR-LSP for which an upstream request is still pending.

The encoding for the CR-LDP Label Mapping Message is as follows:

Table 3-2 Label Mapping Message.

0	Label Mapping (0x0400) (15 bits)	Message Length (16 bits)
Message ID		
FEC TLV		
Label TLV		
Label Request Message ID TLV		
LSPID TLV (CR-LDP, optional)		
ER-TLV (CR-LDP, optional)		
Traffic TLV (CR-LDP, optional)		
Pinning TLV (CR-LDP, optional)		
Resource Class TLV (CR-LDP, optional)		
Pre-emption TLV (CR-LDP, optional)		
Diff-Serv TLV (CR_LDP, optional)		

3.2.3 Notification Message

An LSR sends a Notification message to inform an LDP peer of a significant event. A Notification message signals a fatal error or provides advisory information such as the outcome of processing an LDP message or the state of the LDP session [1].

Establishment of a CR-LSP may fail for a variety of reasons. All such failures are considered advisory conditions and the Notification Message signals them.

Notification Messages carry Status TLVs to specify events being signaled. The Notification Message may carry the LSPID TLV of the corresponding CR-LSP. The encoding of the notification message is as follows:

Table 3-3 Notification Message.

0	Notification (0x0001) (15 bits)	Message Length (16 bits)
Message ID		
Status (TLV)		
ER-TLV (CR-LDP, optional)		
Traffic TLV (CR-LDP, optional)		
Pinning TLV (CR-LDP, optional)		
Resource Class TLV (CR-LDP, optional)		
Pre-emption TLV (CR-LDP, optional)		
Diff-Serv TLV (CR-LDP, optional)		

3.2.4 Label Release Message

An LSR sends a Label Release message to another LSR peer to signal the peer that the LSR no longer will need the FEC→label mapping for the proposed LSP by that peer.

3.2.5 Label Withdraw Message

An LSR sends a Label Withdraw Message to an LSR peer to signal the peer that the peer will not use specific FEC-label mappings the LSR had previously advertised. That will erase the FEC → label mapping entry from the ILM and FTN map.

3.2.6 Label Abort Request Message

The Label Abort Request message may be used to stop a pending Label Request message.

3.3 Protocol Specification

In this specification, the following TLVs are defined:

- Explicit Route TLV
- Explicit Route Hop TLV
- Traffic Parameters TLV
- Preemption TLV
- LSPID TLV
- Route Pinning TLV
- Resource Class TLV
- CR-LSP FEC TLV

3.3.1 Explicit Route TLV (ER-TLV)

The ER-TLV is an object that specifies the path to be taken by the LSP being established. It is composed of one or more Explicit Route Hop TLVs (ER-Hop TLVs) defined in Section 3.3.1.1 [1, 11].

Table 3-3 Explicit Route TLV (ER-TLV)

0	0	Type = 0x0800 (14 bits)	Length (16 bits)
ER-Hop TLV 1			
ER-Hop TLV 2			
…………			
ER-Hop TLV n			

Type

A fourteen-bit field carrying the value of the ER-TLV Type = 0x0800.

Length

Specifies the length of the value field in bytes.

3.3.1.1 Explicit Route Hop TLV (ER-Hop TLV)

The contents of an ER-TLV are a series of variable length ER-Hop TLVs. A node receiving a label request message including an ER-Hop type that is not supported MUST not progress the label request message to the downstream LSR and MUST send back a "No Route" Notification Message.

Each ER-Hop TLV has the form:

Table 3-4 Explicit Route Hop TLV (ER-Hop TLV)

0	0	Type (14 bits)	Length (16 bits)
L	Content //		

ER-Hop Type

A fourteen-bit field carrying the type of the ER-Hop contents.

Currently defined values are:

Value	Type
0x0801	IPv4 prefix
0x0802	IPv6 prefix
0x0803	Autonomous system number
0x0804	LSPID

Length

Specifies the length of the value field in bytes.

L bit

The L bit in the ER-Hop is a one-bit attribute. If the L bit is set, then the value of the attribute is "loose." Otherwise, the value of the attribute is "strict". For brevity, we say that if the value of the ER-Hop attribute is loose then it is a "loose ER-Hop". Otherwise, it is a "strict ER-Hop".

Further, we say that the abstract node of a strict or loose ER-Hop is a strict or a loose node, respectively. Loose and strict nodes are always interpreted relative to their prior abstract nodes. The path between a strict node and its prior node must include only network nodes from the strict node and its prior abstract node.

Contents

A variable length field containing a node or abstract node, which is one of the consecutive nodes, which makes up the explicitly routed LSP.

3.3.2 CR-LDP Extensions for Differentiated Services (Diff-Serv) Support

The MPLS architecture does not assume a single label distribution protocol. [1] defines the Label Distribution Protocol and it is used for establishment of label switched paths (LSPs) in MPLS networks. Diff TLV is used in LDP to establish label switched path (LSPs) supporting Differentiated Services (Diff-Serv) in MPLS networks.

The new Diff-Serv TLV is optional with respect to LDP. A Diff-Serv capable LSR supporting E-LSPs, which uses the Preconfigured EXP←→PHB mapping in compliance with this specification, may support the Diff-Serv TLV. A Diff-Serv capable LSR supporting E-LSPs, which uses the signaled EXP←→PHB mapping in compliance with this specification, must support the Diff-Serv TLV. A Diff-Serv capable LSR supporting L-LSPs in compliance with this specification must support the Diff-Serv TLV.

3.3.2.1 Diff-Serv TLV for E-LSP

The Diff-Serv TLV has the following formats[10]:

Table 3-6 Diff-Serv TLV for E-LSP

<table>
<tr><td>U</td><td>F</td><td>Diff-Serv (0x901)
(14 bits)</td><td colspan="2">Length
(16 bits)</td></tr>
<tr><td>T</td><td colspan="3">Reserved</td><td>MAPnb
(4 bits)</td></tr>
<tr><td colspan="5">MAP (1)</td></tr>
<tr><td colspan="5">............</td></tr>
<tr><td colspan="5">MAP (MAPnb)</td></tr>
</table>

T: 1 bit

LSP Type. This is set to 0 for an E-LSP

Reserved: 27 bits

This field is reserved. It must be set to zero on transmission and must be ignored on receipt.

MAPnb: 4 bits

Indicates the number of MAP entries included in the DIFFSERV Object. This can be set to any value from 1 to 8.

MAP: 32 bits

Each MAP entry defines the mapping between one EXP field value and one PHB. The MAP entry has the following format:

Reserved	EXP (3 bits)	PHBID (16 bits)

Reserved: 13 bits

This field is reserved. It must be set to zero on transmission and must be ignored on receipt.

EXP: 3 bits

This field contains the value of the EXP field for the EXP←→PHB mapping defined in this MAP entry.

PHBID: 16 bits

This field contains the PHBID of the PHB for the EXP←→PHB mapping defined in this MAP entry.

3.3.2.2 Diff-Serv TLV for an L-LSP

Table 3-7 Diff-Serv TLV for an L-LSP.

U	F	Type = PSC (0x901)	Length
T	Reserved		PSC

T: 1 bit

LSP Type. This is set to 1 for an L-LSP[10].

Reserved: 15 bits

This field is reserved. It must be set to zero on transmission and must be ignored on receipt.

PSC: 16 bits

The PSC indicates a PHB Scheduling Class to be supported by the LSP.

Diff-Serv Status Code Values

The following values are defined for the Status Code field of the Status TLV[10]:

Table 3-8 Diff-Serv Status Code Values.

Error Status Code	Status Data
Unexpected Diff-Serv TLV	0x01000001
Unsupported PHB	0x01000002
Invalid EXP←→PHB mapping	0x01000003
Unsupported PSC	0x01000004
Per-LSP context allocation failure	0x01000005

3.3.3 Traffic Parameters TLV

The following sections describe the CR-LSP Traffic Parameters. The required characteristics of a CR-LSP are expressed by the Traffic Parameter values [17, 11].

A Traffic Parameters TLV is used to signal the Traffic Parameter values. The Traffic Parameters are defined in the subsequent sections.

The Traffic Parameters TLV contains a Flags field, a Frequency, a Weight, and the five Traffic Parameters PDR, PBS, CDR, CBS, EBS. The Traffic Parameters TLV is shown below:

Table 3-9 Traffic Parameters TLV.

<table>
<tr><td>0</td><td>0</td><td colspan="2">Type = 0x0810
(14 bits)</td><td colspan="2">Length = 24
(16 bits)</td></tr>
<tr><td colspan="3">Flags
(8 bits)</td><td>Frequency
(8 bit)</td><td>Reserved</td><td>Weight
(8 bit)</td></tr>
<tr><td colspan="6">Peak Data Rate (PDR)</td></tr>
<tr><td colspan="6">Peak Burst Size (PBS)</td></tr>
<tr><td colspan="6">Committed Data Rate (CDR)</td></tr>
<tr><td colspan="6">Committed Burst Size (CBS)</td></tr>
<tr><td colspan="6">Excess Burst Size (EBS)</td></tr>
</table>

Type

A fourteen-bit field carrying the value of the Traffic Parameters TLV Type = 0x0810.

Length

Specifies the length of the value field in bytes = 24.

Flags

The Flags field is shown below:

Reserve	F6	F5	F4	F3	F2	F1

Reserved - These bits are reserved. Zero on transmission. Ignored on receipt.

F1 - Corresponds to the PDR.

F2 - Corresponds to the PBS.

F3 - Corresponds to the CDR.

F4 - Corresponds to the CBS.

F5 - Corresponds to the EBS.

F6 - Corresponds to the Weight.

Each flag Fi is a Negotiable Flag corresponding to a Traffic Parameter. The Negotiable Flag value zero denotes NotNegotiable and value one denotes Negotiable.

Frequency

The Frequency field is coded as an 8 bit unsigned integer with the following code points defined:

0- Unspecified

1- Frequent

2- VeryFrequent

3-255 - Reserved

Reserved - Zero on transmission. Ignored on receipt.

The Frequency specifies at what granularity the CDR allocated to the CR-LSP is made available. The value VeryFrequent means that the available rate should average at least the CDR when measured over any time interval equal to or longer than the shortest packet time at the CDR. The value Frequent means that the available rate should average at least the CDR when measured over any time interval equal to or longer than a small number of shortest packet times at the CDR [11].

Weight

An 8 bit unsigned integer indicating the weight of the CR-LSP. Valid weight values are from 1 to 255. The value 0 means that weight is not applicable for the CR-LSP. The weight determines the CR-LSP is relative share of the possible excess bandwidth above its committed rate. The definition of "relative share" is MPLS domain specific.

3.3.3.1 Traffic Parameters

Each Traffic Parameter is encoded as a 32-bit IEEE single-precision floating-point number. A value of positive infinity is represented as an IEEE single-precision floating-point number with an exponent of all ones (255) and a sign and mantissa of all zeros. The values PDR and CDR are in units of bytes per second. The values PBS, CBS and EBS are in units of bytes. The value of PDR must be greater than or equal to the value of CDR in a correctly encoded Traffic Parameters TLV [11].

3.3.3.2 Peak Data Rate

The Peak Rate defines the maximum rate at which traffic should be sent to the CR-LSP. The Peak Rate is useful for the purpose of resource allocation. If resource allocation within the MPLS domain depends on the Peak Rate value then it should be enforced at the ingress to the MPLS domain. The Peak Rate is defined in terms of the two Traffic Parameters PDR and PBS.

3.3.3.3 Committed Data Rate

The Committed Rate defines the rate that the MPLS domain commits to be available to the CR-LSP. The Committed Rate is defined in terms of the two Traffic Parameters CDR and CBS.

3.3.3.4 Excess Burst Size

The Excess Burst Size may be used at the edge of an MPLS domain for the purpose of traffic conditioning. The EBS may be used to measure the extent by which the traffic sent on a CR-LSP exceeds the committed rate. The possible traffic conditioning actions, such as passing, marking or dropping, are specific to the MPLS domain.

3.3.4 Preemption TLV

The default value of the setup and holding priorities should be in the middle of the range (e.g., 4) so that this feature can be turned on gradually in an operational network by increasing or decreasing the priority starting at the middle of the range.

Since the Preemption TLV is an optional TLV, LSPs that are setup without an explicitly signaled preemption TLV should be treated as LSPs with the default setup and holding priorities (e.g. 4).

When an established LSP is preempted the LSR that initiates the preemption sends a Withdraw Message upstream and a Release Message downstream.

When an LSP in the process of being established (outstanding Label Request without getting a Label Mapping back) is preempted, the LSR that initiates the preemption sends a Notification Message upstream and an Abort Message downstream.

Table 3-10 Preemption TLV.

<table>
<tr><td>0</td><td>0</td><td colspan="2">Type = 0x0820
(14 bit)</td><td>Length=4
(16 bit)</td></tr>
<tr><td colspan="3">SetPrio</td><td>HoldPrio</td><td>Reserved</td></tr>
</table>

Type

A fourteen-bit field carrying the value of the Preemption-TLV Type = 0x0820.

Length

Specifies the length of the value field in bytes = 4.

Reserved

Zero on transmission. Ignored on receipt.

SetPrio

A setup priority of value zero (0) is the priority assigned to the most important path. It is referred to as the highest priority. Seven (7) is the priority for the least important path. The higher the setup priority, the more paths CR-LDP can bump to set up the path. The default value should be 4.

HoldPrio

A holding priority of value zero (0) is the priority assigned to the most important path. It is referred to as the highest priority. Seven (7) is the priority for the least important path. The default value should be 4. The higher the holding priority, the less likely it is for CR-LDP to reallocate its bandwidth to a new path.

3.3.5 LSPID TLV

LSPID is a unique identifier of a CR-LSP within an MPLS network. The LSPID is composed of the ingress LSR Router ID (or any of its own Ipv4 addresses) and a locally unique CR-LSP ID to that LSR. The LSPID is useful in network management, in CR-LSP repair, and in sing an already established CR-LSP as a hop in an ER-TLV.

An "action indicator flag" is carried in the LSPID TLV. This "action indicator flag" indicates explicitly the action that should be taken if the LSP already exists on the LSR receiving the message.

After a CR-LSP is set up, its bandwidth reservation may need to be changed by the network operator, due to the new requirements for the traffic carried on that CR-LSP. The "action indicator flag" is used indicate the need to modify the bandwidth and possibly other parameters of an established CR-LSP without service interruption[11].
This feature has application in dynamic network resources management where traffic of different priorities and service classes is involved.

Table 3-11 LSPID TLV.

0	0	Type = 0x0821 (14 bit)		Length=4 (16 bit)
Reserved			ActFlg (4 bit)	Local CR-LSP ID (16 bit)
Ingress LSR Router ID (32 bit)				

Type

A fourteen-bit field carrying the value of the LSPID-TLV Type = 0x0821.

Length

Specifies the length of the value field in bytes = 4.

ActFlg

Action Indicator Flag: A 4-bit field that indicates explicitly the action that should be taken if the LSP already exists on the LSR receiving the message. A set of indicator code points is proposed as follows:

0000: indicates initial LSP setup

0001: indicates modify LSP

Reserved

Zero on transmission. (Ignored)

Local CR-LSP ID

The Local LSP ID is an identifier of the CR-LSP locally unique within the Ingress LSR originating the CR-LSP.

Ingress LSR Router ID

An LSR may use any of its own IPv4 addresses in this field.

3.3.6 Resource Class (Color) TLV

The Resource Class as defined in [3] is used to specify which links are acceptable by this CR-LSP. This information allows for the network topology to be pruned.

Table 3-12 Resource Class (Color) TLV.

0	0	Type = 0x0822 (14 bit)	Length=4 (16 bit)
RsCls (32 bit)			

Type

A fourteen-bit field carrying the value of the ResCls-TLV Type = 0x0822.

Length

Specifies the length of the value field in bytes = 4.

RsCls

The Resource Class bit mask indicating which of the 32 "administrative groups" or "colors" of links the CR-LSP can traverse.

3.3.7 CR-LSP FEC Element

A new FEC element is introduced in this specification to support CR-LSPs. A FEC TLV containing a FEC of Element type CR-LSP (0x04) is a CR-LSP FEC TLV. The CR-LSP FEC Element is an opaque FEC to be used only in Messages of CR-LSPs [1].

A single FEC element must be included in the Label Request Message. The FEC Element should be the CR-LSP FEC Element. However, one of the other FEC elements (Type=0x01, 0x02, 0x03) defined in [1] may be in CR-LDP messages instead of the CR-LSP FEC Element for certain applications. A FEC TLV containing a FEC of Element type CR-LSP (0x04) is a CR-LSP FEC TLV.

FEC Element	Type	Value	Type name
CR-LSP	0x04	No value; i.e., 0 value octets;	

The CR-LSP FEC TLV encoding is as follows:

Table 3-13 CR-LSP FEC Elements

0	0	Type = 0x0100 (14 bit)	Length=1 (16 bit)
CR-LSP (4 bits)			

Type

A fourteen-bit field carrying the value of the FEC TLV Type = 0x0100

Length

Specifies the length of the value field in bytes = 1.

CR-LSP FEC Element Type 0x04

TLV Type Name Space

Initial values for this range are specified in the following table:

Table 3-14 TLV Type Name Space.

TLV	Type
Explicite Route TLV	0x0800
Ipv4 Prefix ER-Hop TLV	0x0801
Ipv6 Prefix ER-Hop TLV	0x0802
Autonomous System Number ER-Hop TLV	0x0803
LSP-ID ER-Hop TLV	0x0804
Traffic Parameters TLV	0x0810
Preemption TLV	0x0820
LSPID TLV	0x0821
Resource Class TLV	0x0822
Route Pinning TLV	0x0823
Diff-Serv TLV	0x0901

3.4 Label Forwarding Model for Diff-Serv LSRs for L-LSP

Maintaining Label stack for forwarded packet's BAs, controls the actual Label swapping decision of Diff-Serv LSR. Because we are transporting different OAs of given FEC over different LSPs. Moreover, in Diff-Serv field in IP packet may not be directly accessible to a Diff-Serv LSR, the only way to find the suitable PHB to the received packet and pass this information through the encoded PHB into the transmitted packet is not same as a non-MPLS domain Diff-Serv Router [10].

Thus, in order to describe Label Forwarding by Diff-Serv LSRs, we model the LSR Diff-Serv label switching behavior as comprising four stages:

(1) Incoming PHB Determination

(2) Outgoing PHB Determination with Traffic Conditioning

(3) Label Forwarding

(4) Encoding of Diff-Serv information into Encapsulation Layer (EXP, CLP)

Each stage-process is described in more details in the following sections. Obviously, to enforce the Diff-Serv service differentiation the LSR must also apply the forwarding treatment corresponding to the Outgoing PHB.

This model-process is illustrated below:

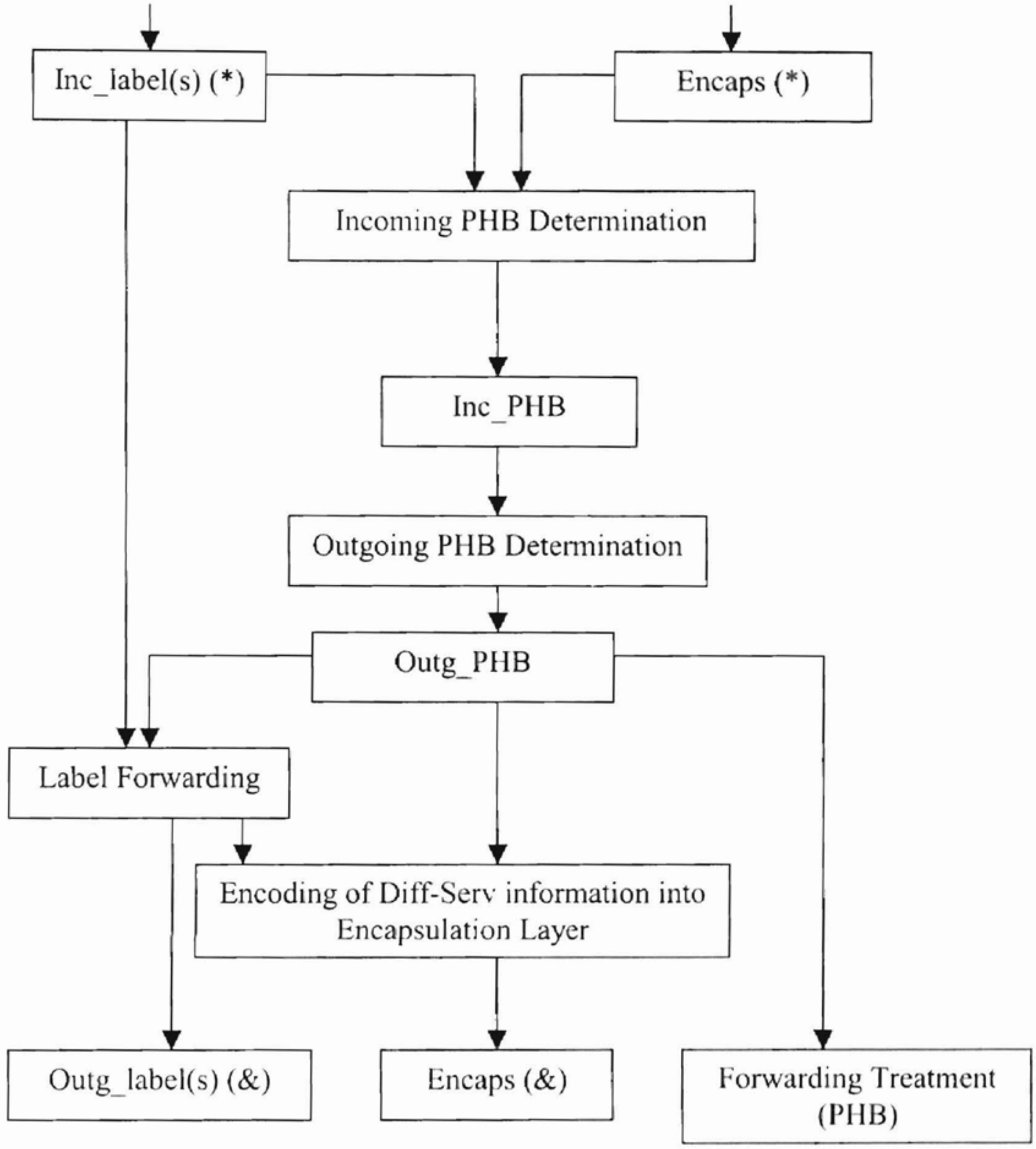

Figure 3-1 Flowchart of the LSR operations.

"Encaps" designates the Diff-Serv related information encoded in the MPLS Encapsulation layer (eg EXP field, ATM CLP)

(*) when the LSR behaves as an MPLS ingress node, the incoming packet may be received unlabelled.

(&) when the LSR behaves as an MPLS egress node, the outgoing packet may be transmitted unlabelled.

The model described above is to show the stepwise functionality of Diff-Serv LSRs in MPLS and non-MPLS Domain.

3.4.1 Incoming PHB Determination

In this stage the LSR process the incoming packet and find out the required QoS and TE parameters. Depending on these parameters it decides the Behavior Aggregate to forward the packet.

3.4.1.1 Incoming PHB Determination Considering a Label Stack Entry

Here, the L-LSP received the incoming packet, to transmit the packet to the next hop it need to know the BAs, OAs and Incoming PHB. All these information is already encoded in the Label entry in the received Label stack of the packet. For that L-LSP uses `Encaps→PHB mapping'.

`EXP→PHB mapping'

The 'Encaps→PHB mapping' is a predefined mapping to decide the PHB.

If both `Encaps→PHB mapping' and `EXP→PHB mapping' are of same kind:

LSR look at the EXP bit field in the Label entry and decide the incoming PHB from the EXP→PHB mapping [10].

If LSR support the L-LSPs over the LAN or PPP interface to terminate the shim Layer over the ingress interface over this incoming LSP, that is neither an ATM domain nor any other domain, then LSR perform the 'Encaps→PHB mapping' in following way:

- It is same as the `EXP→PHB mapping'.
- In this mapping the EXP (Encaps) field has direct mapping with PSC on this LSP, which is used to determine the PHB:

Mandatory EXP/PSC → PHB mapping

EXP Field	PSC		PHB
000	DF	→	DF
000	CSn	→	CSn
001	AFn	→	AFn1
010	AFn	→	AFn2
011	AFn	→	AFn3
000	EF	→	EF

For example, if the incoming label corresponds to an L-LSP supporting the AF2 PSC, then the `Encaps→PHB mapping' will be populated with:

EXP Field		PHB
001	→	AF21
010	→	AF22
011	→	AF23

If the LSR terminates the MPLS Shim Layer over this incoming L-LSP interface and the L-LSP ingresses interface is an ATM interface, then the `Encaps→PHB mapping' is performed in the following way:

-It should actually be the `EXP→PHB mapping'. Alternative optional ways of populating the `Encaps→PHB mapping' might be defined in the future (e.g., using a 'CLP/EXP→ PHB mapping').

-When the `Encaps→PHB mapping' is an `EXP→PHB mapping', this `EXP→PHB mapping' is a function of the PSC, which is carried on the L-LSP, and must use the relevant mapping entries for this PSC from the Mandatory EXP/PSC→PHB Mapping defined as shown above[10].

If both `Encaps→PHB mapping' and `EXP→PHB mapping' are of same kind:

LSR look at the EXP bit field in the Label entry and decide the incoming PHB from the EXP→PHB mapping.

- It is same as the `EXP→PHB mapping'.

- In this mapping the EXP (Encaps) field has direct mapping with PSC on this LSP, which is used to determine the PHB:

Mandatory EXP/PSC → PHB mapping

EXP Field	PSC		PHB
000	DF	→	DF
000	CSn	→	CSn
001	AFn	→	AFn1
010	AFn	→	AFn2
011	AFn	→	AFn3
000	EF	→	EF

An Edge-LSR of an ATM-MPLS domain is an example of LSR terminating the shim layer over ingress ATM interface.

`CLP→PHB mapping'

IF both `Encaps→PHB mapping' and `CLP→PHB mapping' are of same kind: LSR look at the CLP bit field in the ATM Layer encapsulation and decide the incoming PHB from the EXP→PHB mapping.

If the LSR does not terminate an MPLS Shim Layer over this incoming label interface and uses ATM encapsulation (i.e. Tunneling through an ATM-LSR), then the `Encaps→PHB mapping' for this incoming L-LSP is performed in following way:

-It is same as a `CLP→PHB mapping'

- In this mapping the CLP (Encaps) field has direct mapping with PSC on this LSP, which is used to determine the PHB from the Default CLP/PSC→PHB Mapping:

Default CLP/PSC → PHB Mapping

CLP Bit	PSC		PHB
0	DF	→	DF
0	CSn	→	CSn
0	AFn	→	AFn1
1	AFn	→	AFn2
0	EF	→	EF

For example if the incoming label corresponds to an L-LSP supporting the AF2 PSC, then the 'Encaps→PHB mapping' should be done with:

CLP Field		PHB
0	→	AF21
1	→	AF22

3.4.1.2 Incoming PHB Determination Considering IP Header

When the incoming packet is IP packet, which does not have any label entry, then the incoming PHB determination depends on the supported Diff-Serv tunneling model. The LSR uses the Diff-Serv field of the IP header to decide the incoming PHB. This is same function as done in IP Diff-Serv Router, which is not in MPLS domain [10].

3.4.2 Outgoing PHB Determination with Traffic Conditioning

To provide the support of the QoS and TE, Traffic management policy is most important stage. This stage includes the traffic conditioning, BA's demotion or promotion. To make MPLS capable of supporting the Diff-Serv, we have encoded all of this information into PHB, and enforced PHB to convey this information to downstream LSR. It may happen that the Incoming PHB and the Out going PHB are different for the same packet.

Traffic conditioning is same as Traffic Engineering. For a moment assume that the traffic conditioning stage is not present, and then the "outgoing PHB" is simply identical to the "incoming PHB". Performing the `Set of PHB→Encaps mappings' for an outgoing L-LSP.

This section is kind of opposite of the one we did in "Incoming PHB determination" stage. This section defines how the `PHB→Encaps mappings' can be used to encode the Diff-Serv Information in the Label at the time of label setup for an outgoing L-LSP.

If LSR is in MPLS domain and it is using the MPLS Shim header Label over this outgoing L-LSP, then it has to use the PHB→EXP mapping for encoding the PHB information. This EXP bit field has direct mapping with PSC of the LSR.

The Mandatory PHB→EXP Mapping is defined by:

Mandatory PHB→EXP Mapping

PHB		EXP Field
DF	→	000
CSn	→	000
AFn1	→	001
AFn2	→	010
AFn3	→	011
EF	→	000

For example if the outgoing label corresponds to an L-LSP supporting the AF2 PSC, then the following `PHB→EXP mapping' is added into the `Set of PHB→Encaps mappings' [10]:

PHB		EXP Field
AF21	→	001
AF22	→	010
AF23	→	011

`PHB→CLP mapping'

If the L-LSP is egressing on an ATM interface, then there are three different cases:

1. ATM interface with no Label Controlled.

2. ATM interface with Label Controlled.

3. It is an ATM-LSR.

1. If the L-LSP is egressing over an ATM interface, which is not label- controlled, the `PHB→CLP mapping' is defined as:

PHB		CLP Field
AF11	→	0
AF12	→	1
AF13	→	1
EF	→	0

2. If the L-LSP is egressing over an LC-ATM interface; the `PHB→CLP mapping' is performed as described below. CLP defines a function of the PSC supported on this L-LSP, and should use the proper mapping entries for this PSC from the Default PHB→CLP Mapping defined by:

Default PHB→CLP Mapping

PHB		CLP Bit
DF	→	0
CSn	→	0
AFn1	→	0
AFn2	→	1
AFn3	→	1
EF	→	0

3. If the LSR is a frame-based LSR (ATM-LSR) supporting an L-LSP egressing over an ATM interface, then the `Set of PHB→Encaps mappings' contains both a `PHB→EXP mapping' and a `PHB→CLP mapping' [10].

3.4.3 Label Forwarding

LSRs perform Label PUSH, POP and SWAPP operation on the incoming labeled packets in MPLS domain. It uses an Incoming Label Map (ILM), which map contains the mapping information of each incoming label to one or multiple NHLFEs. If the incoming packet is unlabelled, then LSR also performs the label positioning on the packets using FEC-to-NHLFEs MAP (FTN). In this map all the FEC is mapped to one or multiple NHLFEs. All this details are in [2].

Diff-Serv information for a label is defined as comprising:

- `LSP type (i.e. E-LSP or L-LSP)'
- `Supported PHBs'
- `Encaps→PHB mapping' for an incoming label
- `Set of PHB→Encaps mappings' for an outgoing label

All these Diff-Serv information is encoded in the ILM for each incoming label. According to the present specification, NHLFE also contain any other information needed to treat the packet properly. For each outgoing label, the NHLFE contain all the Diff-Serv information, which can be Swapped or pushed by the LSRs. This Diff-Serv Context information is performed, estimated and encoded into the ILM and the FTN at time of label establishment. If the label corresponds to an L-LSP, the `supported PHBs' is populated with the set of PHBs forming the PSC that is signaled at LSP set-up.

The incoming label (i.e. FEC) mapped to multiple NHLFEs, because different NHLFEs corresponds to different sets of PHBs for egress labels. When we have this kind of one to many mapping, the LSR have to decide the proper NHLFEs to support the Diff-Serv context for the outgoing PHB of the forwarded packet. In deciding the proper NHLFEs, the LSR considered the load balancing of BAs over multiple LSPs.

3.4. 4 Encoding Diff-Serv Information

3.4.4.1 Encoding Diff-Serv Information into Encapsulation Layer

This stage describes how to encode the fields like MPLS shim EXP, ATM CLP etc. to convey the Diff-Serv to the next hop LSR. For encoding the Diff-Serv information into the MPLS domain within the label is done with the help of the `Set of PHB→Encaps mappings' for outgoing L-LSP. `Set of PHB→Encaps mappings' is performed as shown above.

The LSR first determines the `Set of PHB→Encaps mappings' of the Diff-Serv Context associated with the corresponding label in the NHLFE and then performs corresponding encoding as specified above [10].

3.4. 4.2 Encoding Diff-Serv Information into Transmitted IP Header

To convey the Diff-Serv Information into the transmitted IP packet, non-MPLS Diffe-Serv Router uses Outgoing PHB information to encode the Diff-Serv information into the DS field of the IP header.

Now we will see three different cases to see the operation of LSR.

(1) Label forwarding steps

LSR 2 wants to decide the Label for LSP between LSR2 and LSR3 as shown in the figure 3-2. LSR2 has to perform the steps as shown in figure 3-3.

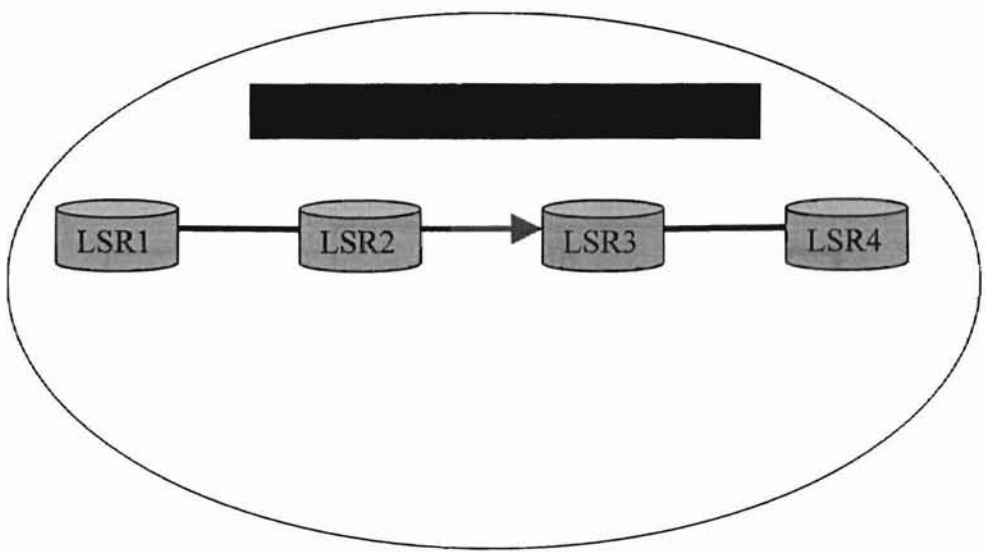

Figure 3-2 LSP between LSR2 and LSR3.

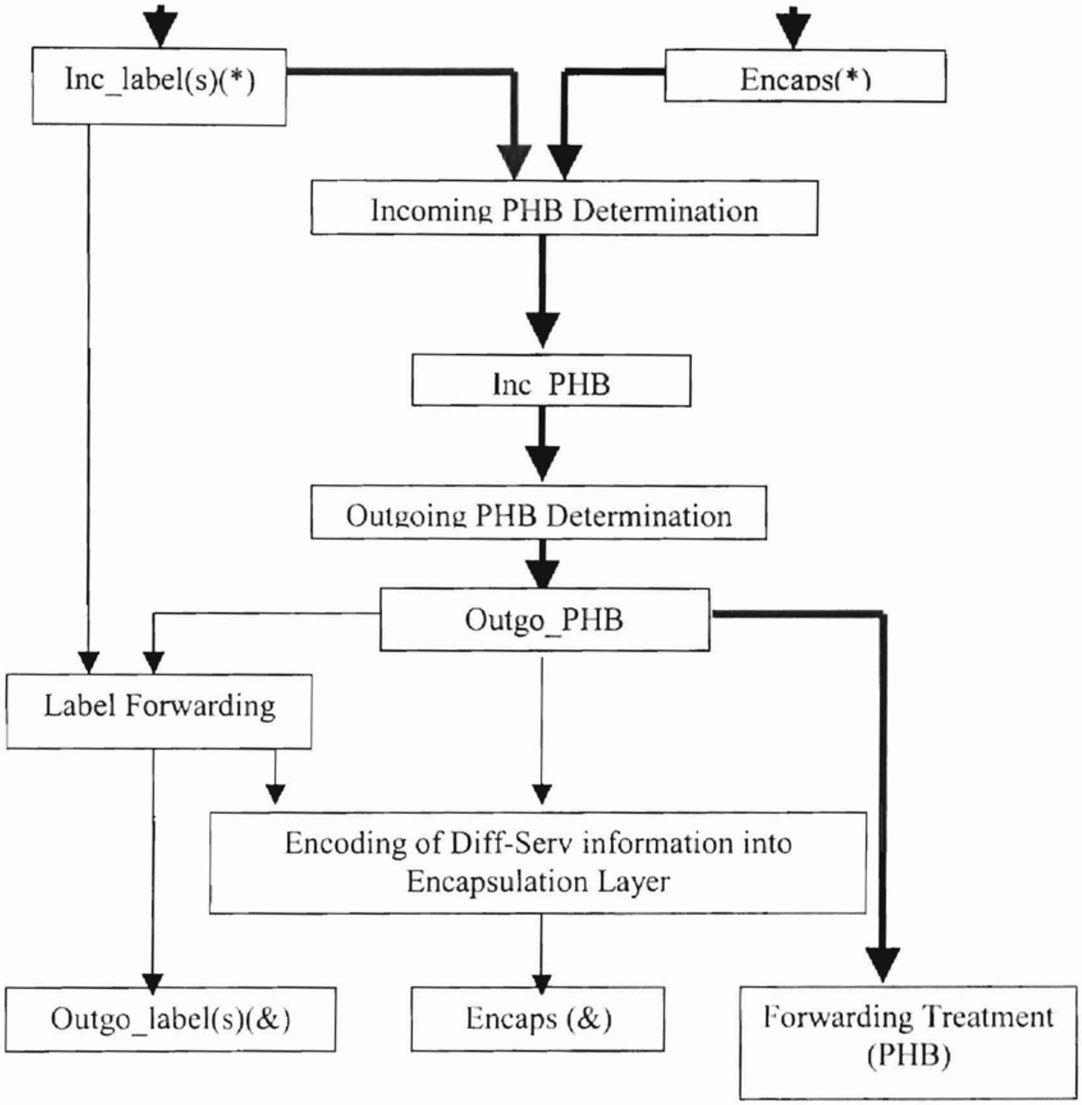

Figure 3-3 Steps of LSR for Forwarding the Label.

(2) Forwarding the Packets in MPLS Domain

If we want to forward the labeled packet through the MPLS domain then the LSR has to perform the following steps as shown in figure 3-4.

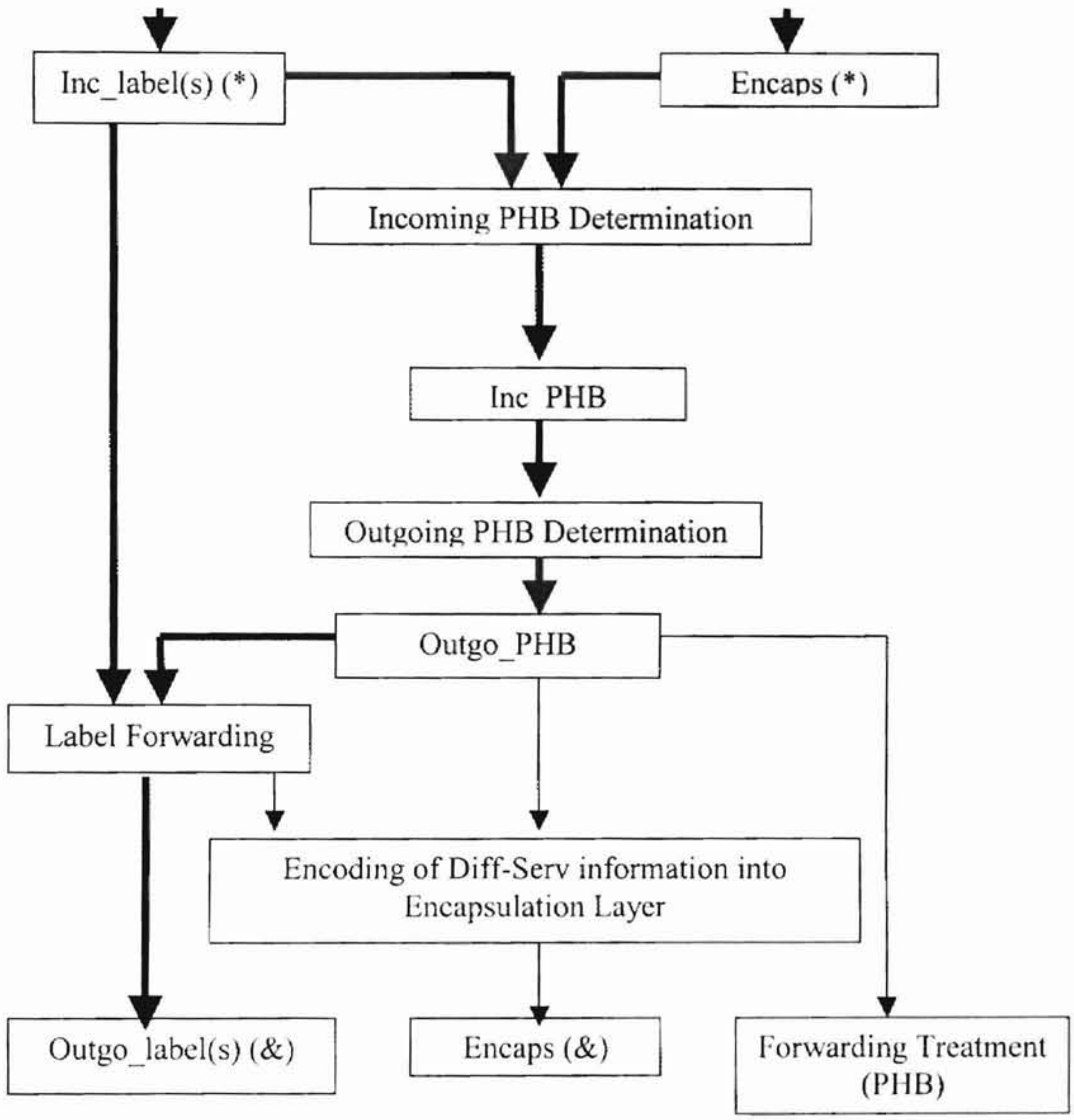

Figure 3-4 Steps of LSR for Forwarding the Labeled packet.

(3) Encoding the Diff-Serv into encapsulation layer

If our packet is traveling from MPLS domain to ATM/ATM-PNNI domain then Diff-Serv should be encoded in to applicable unit ATM. Figure 3-5 represent the packet traveling from MPLS to ATM domain. Steps followed by LSR to encode the Diff-Serv in Encapsulation layer are shown in figure 3-6.

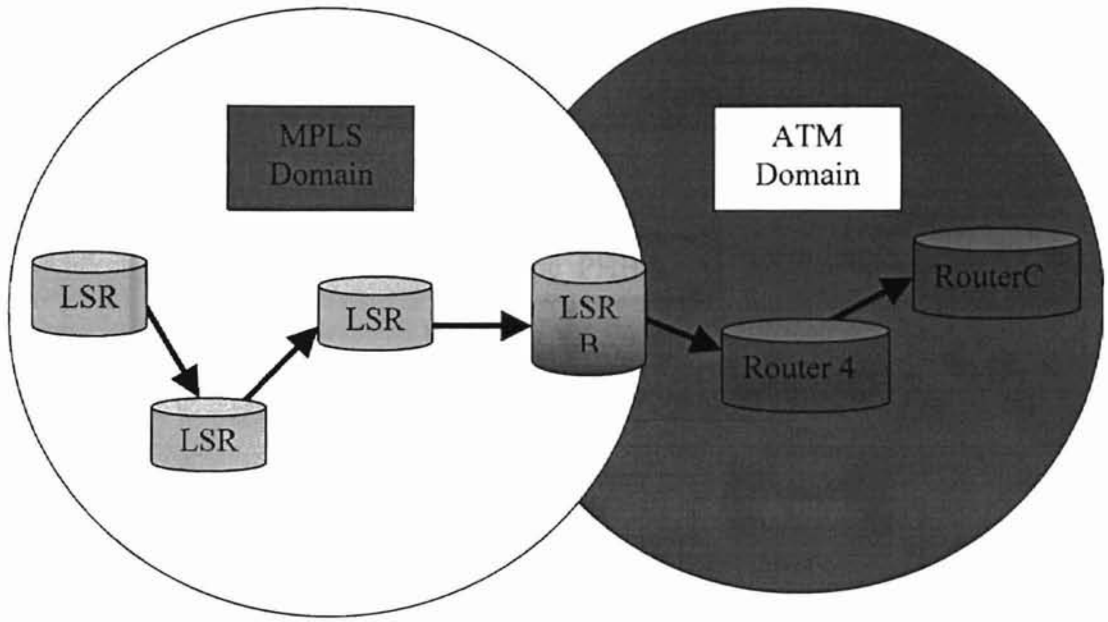

Figure 3-5 Packets from MPLS to ATM-PNNI domain.

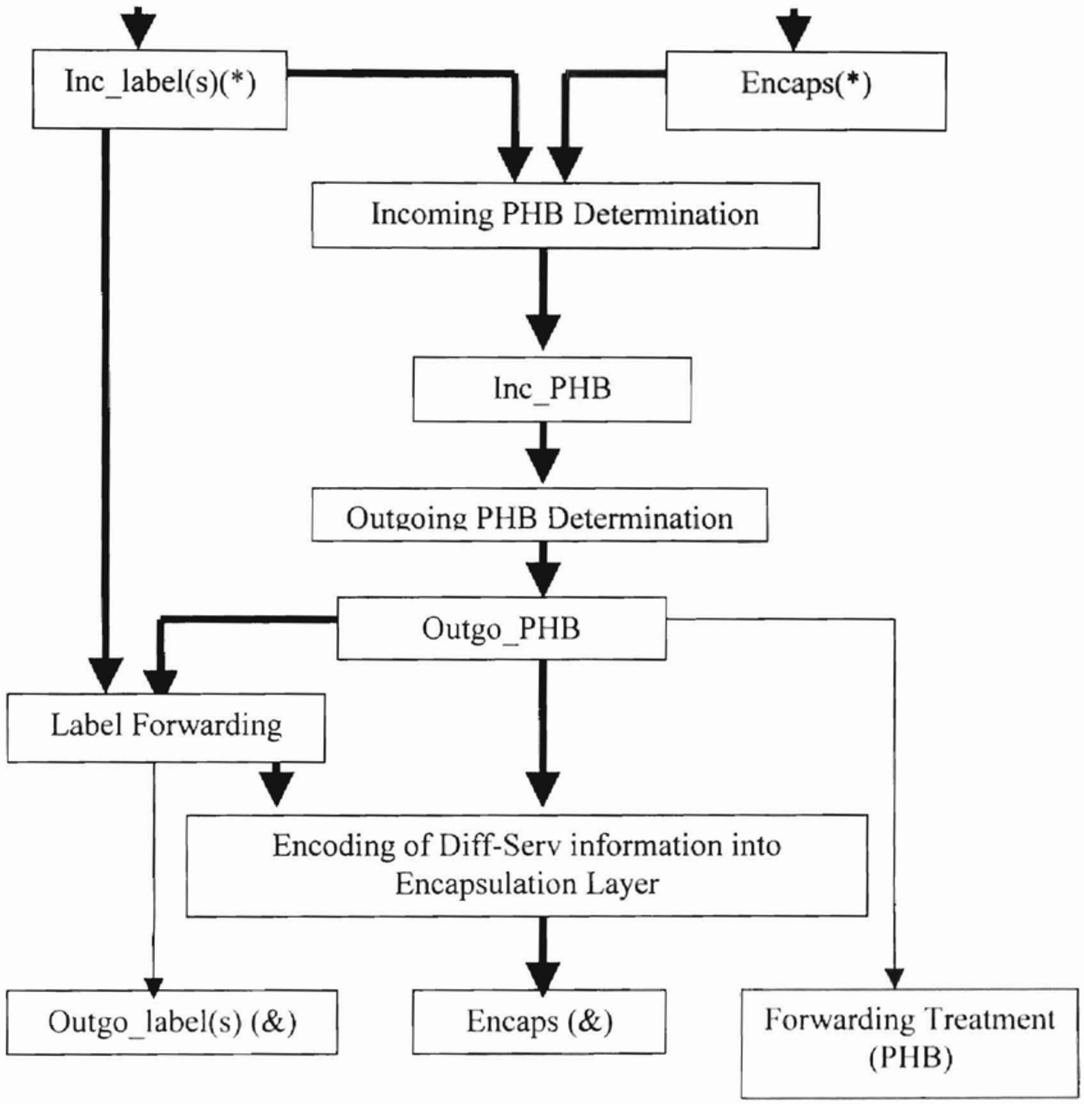

Figure 3-6 Steps of LSR to encode the Diff-Serv into Encapsulation Layer.

3.4.5 Diff-Serv supporting MPLS LSR

By using the Traffic TLV and Diff-Serv TLV MPLS router can perform packet forwarding. But use of Traffic TLV only explains the supportive type & range of traffic rates and the ranges of the max and min burst traffic. While Diff-Serv TLV provides the information of packet loss ratio and packet delay variation for high quality QoS in this different type of traffic (e.g. VBR, CBR, ABR, UBR). Both these TLVs work independently, but Diff-Serv TLV is only required for real time application of voice or video. For that LSR uses the RTP (Real Time Protocol)/RTCP (Real Time Control Protocol) to actually utilize the Diff-Serv TLV to achieve the controllability for to provide the adaptive traffic engineering QoS/CoS features [16].

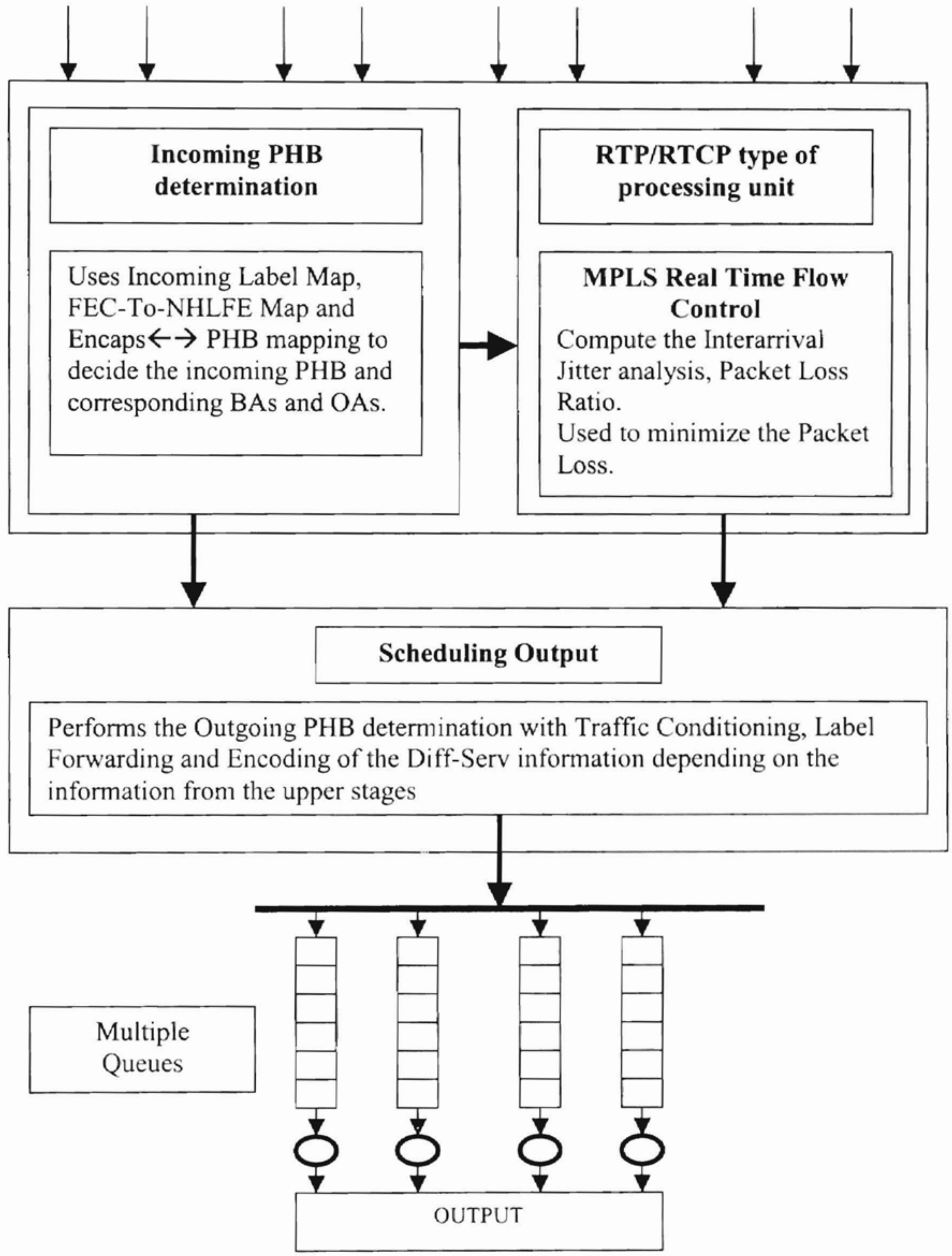

Figure 3-7 MPLS LSR Operation.

3.5 MPLS Applications:

• IP+ATM Integration

MPLS fully integrates IP services directly on ATM switches. The IP routing and LDP software resides directly on ATM switches. Thus MPLS allows ATM switches to optimally support IP multicast, IP class of service, RSVP, and Virtual Private Networks. Optimal integration of IP+ATM means that MPLS is far more scalable and far less complex than overlay schemes.

• IP Virtual Private Network (VPN) Services

A VPN service is the infrastructure of a managed Intranet or Extranet service offered by a provider to many corporate customers. These are often massive IP networks. MPLS, in combination with the Border Gateway Protocol (BGP), allows one provider network to support thousands of customer's VPNs. In this way, MPLS with BGP offers a very flexible, scalable, and manageable way of providing VPN services on both ATM and packet-based equipment. Even on small provider's networks, the flexibility and manageability of MPLS+BGP VPN services are a major benefit.

• IP Explicit Routing and Traffic Engineering (TE)

An important problem in current IP networks is the lack of ability to finely adjust IP traffic flows to make best use of available network bandwidth. Also absent are related capabilities to send selected flows down selected paths, for example, to select protected trunks for particular classes of traffic. MPLS uses Label Switched Paths (LSPs), a type of lightweight VC. These can be set up on both ATM and packet-based equipment. The IP Traffic Engineering capability of MPLS uses special LSPs to finely adjust IP traffic flows.

In chapter III, we have use the concept of LSPs from chapter II to define the LSR operation. We will use the Label Request Message, Label Mapping Message and Notification Messages to define the L-LSP or E-LSP establishment in chapter V. To use these messages precisely, the described TLV like Diff-Serv TLV and Traffic TLV information will be helpful.

The chapter III also defines the exact operation of MPLS LSR to forward the packet or label and encode the Diff-Serv information in the Encapsulation Layer. This will help to understand the chapter V procedure in detail. The label forwarding model for Diff-LSRs for E-LSP will be same as describe for L-LSP in this chapter.

We will also use the 'PHB→CLP mapping' and 'CLP→PHB mapping' describe in this chapter into chapter V.

CHAPTER IV

LITERATURE REVIEW

This chapter provide introduction about ATM-PNNI hierarchy, features of ATM-PNNI. ATM-PNNI routing overview is also presented here. To establish point-to-point call/connection different control messages are used in ATM-PNNI. The function of those messages is described. To establish the path for communication in ATM-PNNI we have to use SET-UP and CONNECT message. Message format of SET-UP and CONNECT is also mentioned.

To provide the support of Diff-Serv in ATM-PNNI networks, the Traffic of the network is divided into different classes. Those classes are presented too. Lastly, each field of Extended QoS parameters has been shown for SET-UP and CONNECT messages.

4.1 Asynchronous Transmission Mode-Private Network-to-Network Interface ATM-PNNI Hierarchy

The primary goal of the PNNI hierarchy is scalability. However, you can also use the PNNI hierarchy for other needs, such as creating an administrative boundary. For example, you can use the PNNI hierarchy to hide the internal details of a peer group from ATM switches outside of the peer group [13].

4.2 Features of PNNI

- Point-to-point and point-to-multipoint connections
- Can treat a cloud as a single logical link
- Multiple levels of hierarchy, Scalable for global networking.
- Synchronization of topology databases.
- Reroutes around failed components at connection setup
- Automatic topological discovery. No manual input required.(Summarization of topology state information.
- Connection follows the same route as the setup message(associated signaling)
- Flooding of PTSEs.
- Uses: Cost, capacity, link constraints, propagation delay
- Also uses: Cell delay, Cell delay variation, Current average load, Current peak load
- Discovery of neighbors and link status (Uses both link and node parameters)
- Election of PGLs.
- Supports transit carrier selection
- Supports anycast

The key components of the PNNI hierarchy follow (Terminology)[13]:

- Lowest-level (Child) nodes-A logical node in the lowest level of the PNNI hierarchy.

- Peer group-A group of logical nodes. Each node exchanges information with other members of the group, and all members maintain an identical view of the group.
- Border node: one link crosses the boundary
- Peer group leader (PGL)-A logical node within a peer group that summarizes the peer group and represents it as a single logical node at the next level of the PNNI hierarchy. Node with the highest "leadership priority" and highest ATM address is elected as a leader.
- Continuous process Leader may change any time. PGL acts as a logical group node. Uses same ATM address with a different selector value.
- Logical group node (LGN)-A logical node that represents its lower level peer group in the next higher level peer group. Upon becoming a PGL, the PGL creates a parent LGN to represent the peer group as a single logical node at the next level. The PGL is a logical node within the peer group, and the associated LGN is a logical node in the next higher-level peer group.
- Logical node or Node: A physical node or a logical group node
- Logical links: links between logical nodes
- Peer group ID: Address prefixes up to 13 bytes

The lowest level of the PNNI hierarchy contains lowest-level nodes only. No higher levels are possible if all nodes within a peer group are configured as lowest-level nodes. The peer group, PGL, and LGN define the hierarchy and are needed to create multiple levels of the PNNI hierarchy.

4.3 PNNI Hierarchical Network Topology

Figure 4-1 shows a PNNI hierarchical network topology. In a PNNI hierarchical network, the number of nodes, links, and reachable address prefixes visible from any one ATM switch in the network are reduced exponentially as the flat network is migrated to a hierarchical network.

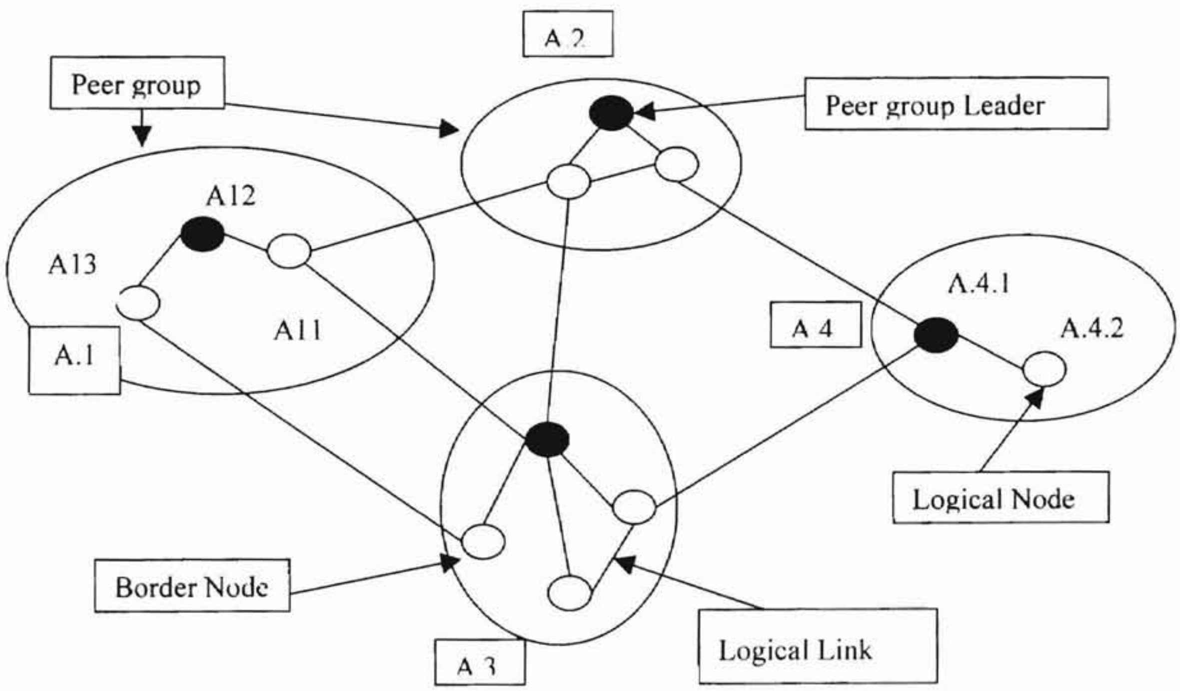

Figure 4-1 PNNI Hierarchical Network Topology.

PNNI hierarchy has some advantages and disadvantages that you should consider before you decide to implement it in your network.

An advantage of PNNI hierarchy is its ability to scale to very large networks. This scalability is because of the exponential reduction in size of the visible topology and amount of received topology state information at each ATM switch in the network. These reductions improve the effectiveness of your network by reducing the control traffic, memory, and processing required by each ATM switch in the network.

A disadvantage of PNNI hierarchy is the loss of information caused by topology aggregation. PNNI performs route computations based on its view of the network topology. Because a hierarchical view of the network is restricted, compared to a nonhierarchical (flat topology) view, routing decisions are not as effective as in a flat topology. In both cases, a path to the destination is selected; however, in most cases the path selected in a flat topology is more efficient. This trade-off between routing efficiency and scalability is not specific to PNNI; it is a known limitation of any hierarchical routing protocol.

4.4 ATM-PNNI Routing Overview

To place calls between ATM end systems, a static routing protocol, or PNNI, a dynamic routing protocol that provides quality of service (QoS) routes to signaling based on the QoS requirements specified in the call setup request [13].

This section provides an overview of ATM/PNNI routing.

Dynamic Routing

PNNI is a dynamic routing protocol for ATM. PNNI is dynamic because it learns the network topology and reachability information with minimal configuration. It automatically adapts to network changes by advertising topology state information.

Source Routing

In a PNNI routing domain, the source ATM switch computes hierarchically complete routes for connection setups. This route information is included in the call set-up signaling message. Where each ATM switch that receives the connection setup message selects the next outgoing interface to which to forward the setup message. This selection is based on the mapping of destination addresses (in a routing table) to outgoing interfaces.

QoS Support

PNNI provides routes that satisfy quality of service (QoS) connection requests. PNNI selects routes through the network based on the administrative weight (AW) and other QoS parameters, such as the available cell rate (AvCR), maximum cell transfer delay (maxCTD), peak-to-peak cell delay variation (CDV), and cell loss ratio (CLR). The primary metric used by PNNI is AW. If a connection requests either maxCTD or CDV or both, PNNI may not be able to compute an optimum route through the network. However, PNNI guarantees a route that meets or exceeds the criteria of all specified QoS parameters.

4.5 Messages for ATM-PNNI point-to-point call and connection control

4.5.1 ALERTING

This message is sent to the upstream router by down-stream router to indicate that called user alerting has been initiated[12].

4.5.2 CALL PROCEEDING

This message is sent to the upstream router by down-stream router to indicate that the requested call/connection establishment has been initiated and no more call establishment information will be accepted.

4.5.3 CONNECT

This message is sent to the upstream router by down-stream router and delivered to the upstream router to indicate call/connection acceptance by the called user.

4.5.4 RELEASE

This message is sent by a network node to an adjacent network node to indicate that it has cleared the connection and is waiting to release the call reference. This message can be sent in both directions.

4.5.5 RELEASE COMPLETE

This message is sent by a network node to an adjacent network node to indicate that it has cleared internally the connection (if any) and released the call reference. This message can be sent in both directions.

4.5.6 SETUP

This message is sent to the downstream router by upstream router to initiate call/connection establishment [12,13].

4.5.7 STATUS

This message is sent by either side in response to a STATUS ENQUIRY message or at any time to report certain error conditions. This message can be sent in both directions.

4.5.8 STATUS ENQUIRY

The STATUS ENQUIRY message may be sent by either side at any time to solicit a STATUS message from the peer entity. Sending a STATUS message in response to a STATUS ENQUIRY message is mandatory. This message can be sent in both directions.

4.5.9 NOTIFY

This message is sent by either side to indicate information pertaining to a call/connection. This message can be sent in both directions.

Out of all these messages SETUP and CONNECT messages are used for the real set-up of the path and reserve the required QoS and Traffic parameters [13].

4.5.10 SETUP Message format:

Table 4-1 SETUP Message format[13]

Information Element	**Type**	**Length**
Protocol discriminator	**M**	**1**
Call reference	**M**	**4**
Message type	**M**	**2**

Message length	**M**	**2**
AAL parameters	**O**	**4-21**
ABR additional parameters	**O**	**4-14**
ABR setup parameters	**O**	**4-36**
Alternative ATM traffic descriptor	**O**	**4-30**
ATM traffic descriptor	**M**	**12-30**
Broadband bearer capability	**M**	**6-7**
Broadband high layer information	**O**	**4-13**
Broadband repeat indicator	**O**	**4-5**
Broadband low layer information	**O**	**4-17**
Called party number	**M**	**2**
Called party soft PVPC or PVCC	**O**	**4-11**
Called party subaddress	**O**	**4-25**
Calling party number	**O**	**4-26**
Calling party soft PVPC or PVCC	**O**	**4-10**
Calling party subaddress	**O**	**4-25**
Connection identifier	**O**	**4-9**
Connection scope selection	**O**	**4-6**
Designated transit list	**M**	**33-546**
Endpoint reference	**O**	**4-7**
End-to-end transit delay	**O**	**4-13**
Extended QoS parameters	**O**	**4-25**
Generic identifier transport	**O**	**4-33**
Minimum acceptable ATM traffic descriptor	**O**	**4-20**
Notification indicator	**O**	**4**
QoS parameter	**O**	**4**
Transit network selection	**O**	**4-9**

M-mandatory O-Optional

4.5.11 CONNECT Message:

Tables 4-2 CONNECT Message[13].

Information Element	**Type**	**Length**
Protocol discriminator	**M**	**1**
Call reference	**M**	**4**
Message type	**M**	**2**
Message length	**M**	**2**
AAL parameters	**O**	**4-11**
ABR additional parameters	**O**	**4-14**
ABR setup parameters	**O**	**4-36**
ATM traffic descriptor	**M**	**4-30**
Broadband low layer information	**O**	**4-17**
Called party soft PVPC or PVCC	**O**	**4-11**
Connected subaddress	**O**	**4-25**
Connected number	**O**	**4-26**
Endpoint reference	**O**	**4-7**
End-to-end transit delay	**O**	**4-7**
Extended QoS parameters	**O**	**4-13**
Generic identifier transport	**O**	**4-33**
Notification indicator	**O**	**4**

M-mandatory O-Optional

4.6 General message format and information element coding

As shown in SETUP & CONNECT message format, in ATM-PNNI, these messages have some mandatory elements and some optional elements [13, 14]. SETUP message is sent by Preceding side to Succeeding side to initiate call/connection establishment.

Mandatory Elements: Protocol discriminator, Call reference, Message type, Message length, ATM traffic descriptor, Broadband bearer capability, Called party number, designated transit list.

Optional Elements: AAL parameters, ABR additional parameters, ABR setup parameters, End-to-end transit delay, Extended QoS parameters, QoS parameter, etc.

Now concentrating on QoS and Extended QoS parameters, QoS classes have been described as following:

QoS classes 0-4 are supported - replace the tables for octets 5 and 6 with the following:

QoS Class Forward (octet 5)

Bits	Meaning
8 7 6 5 4 3 2 1	
0 0 0 0 0 0 0 0	QoS class 0 - Unspecified QoS class (Notes 1,4)
0 0 0 0 0 0 0 1	QoS class 1 (Note 2)
0 0 0 0 0 0 1 0	QoS class 2 (Note 2)
0 0 0 0 0 0 1 1	QoS class 3 (Note 2)

0 0 0 0 0 1 0 0	QoS class 4 (Note 2)
Bits	Meaning
1 1 1 1 1 1 1 1	Reserved by ITU-T for future indication of parameterized QoS (Notes 1, 3)

QoS Class Backward (octet 6)

Bits	Meaning
8 7 6 5 4 3 2 1	
0 0 0 0 0 0 0 0	QoS class 0 - Unspecified QoS class (Notes 1,4)
0 0 0 0 0 0 0 1	QoS class 1 (Note 2)
0 0 0 0 0 0 1 0	QoS class 2 (Note 2)
0 0 0 0 0 0 1 1	QoS class 3 (Note 2)
0 0 0 0 0 1 0 0	QoS class 4 (Note 2)
1 1 1 1 1 1 1 1	Reserved by ITU-T for future indication of parameterized QoS (Notes 1, 3)

Note 1 - This code point is taken from the coding standard value 00. The meaning of this code point applies only for coding standard 00. For coding standard value 11, this code point is reserved by the ATM Forum. If this class is indicated, the network does not guarantee any specific Quality of Service.

Note 2 - The meanings of these code points apply only for the coding standard value 11. For coding standard value 00 these code points are reserved by ITU-T. The ATM Forum reserves the right to assign all values for coding standard value 11. However, these values will be assigned in ascending sequence.

Note 3 - This code point has been reserved by ITU-T for use when individual QoS parameters are defined. The individual parameters would then be contained in octets 7 and higher.

Note 4 - For some public networks, only the Coding Standard value 00 may be allowed at the public UNI [12].

4.6.1 Specified QoS Classes:

A Specified QoS class provides a quality of service to an ATM connection in terms of a subset of the ATM performance parameters defined below. For each Specified QoS class, there is one specified objective value for each performance parameter identified as defined below. Initially, each network should define objective values for a subset of the ATM performance parameters for at least one of the following Service Classes:

Service Class A: Circuit Emulation, Constant Bit Rate Video

Service Class B: Variable Bit Rate Audio and Video

Service Class C: Connection-Oriented Data Transfer

Service Class D: Connectionless Data Transfer

In the future, more "QoS Classes" may be defined for a given "Service Class" described above. The following Specified QoS Classes are currently defined:

Specified QoS Class 1: support a QoS that will meet Service Class A performance requirements and it should yield performance comparable to current digital private line performance.

Specified QoS Class 2: support a QoS that will meet Service Class B performance requirements and it is intended for packetized video and audio in teleconferencing and multi-media applications.

Specified QoS Class 3: support a QoS that will meet Service Class C performance requirements and it is intended for interoperation of connection oriented protocols, such as Frame Relay.

Specified QoS Class 4: support a QoS that will meet Service Class D performance requirements and it is intended for interoperation of connectionless protocols, such as IP, or SMDS.

4.6.2 Unspecified QoS Class

In the Unspecified QoS class, no objective is specified for the performance parameters. However, the network may determine a set of internal objectives for the performance parameters. In fact, these internal performance parameter objectives need not be constant during the duration of a call. Thus, for the Unspecified QoS class there is no explicitly specified QoS commitment on either the CLP=0 or the CLP=1 cell flow. Services using the Unspecified QoS class may have explicitly specified traffic parameters[12,13].

An example application of the Unspecified QoS class is the support of "best effort" service (i.e., UBR).

For this type of service, the user selects the Best-Effort Capability, the Unspecified QoS class, and only the traffic parameter for the PCR on CLP=0+1. This capability can be used to support users that are capable of regulating the traffic flow into the network and to adapt to time-variable available resources.

4.6.3 Extended QoS parameters:

The purpose of the Extended QoS parameters information element is to indicate the individual QoS parameter values acceptable on a per call basis and to indicate the cumulative QoS parameter values. The QoS parameter values included in the Extended QoS parameters information element together with those included in the End-to-end transit delay information element (if present) specify a QoS capability at a UNI 4.0 interface.

The relevant QoS parameters applicable to user data transferred during the data transfer phase on the user plane are defined in the ATM Forum Traffic Management Specification, [13, 14].

The Extended QoS parameter information element is coded as shown in Table below [12, 13].

The maximum length of this information element is 25 octets.

Table 4-3 Extended QoS parameters.

8	7	6	5	4	3	2	1	Octets
Extended QoS Parameters								1
1	1	1	0	1	1	0	0	
Information element identifier								
1 Ext	Coding Standard		Flag	Reserved	Information Elements Action Ind.			2
Length of Extended QoS parameters contents								3
Length of Extended QoS parameters contents(continue)								4
Origin								5
1	0	0	1	0	1	0	0	6
Acceptable Forward Peak-to-Peak Cell Delay Variation Identifier								
Acceptable Forward Peak-to-Peak Cell Delay Variation								6.1
Acceptable Forward Peak-to-Peak Cell Delay Variation(continue)								6.2
Acceptable Forward Peak-to-Peak Cell Delay Variation(continue)								6.3
1	0	0	1	0	1	0	1	7
Acceptable Backward Peak-to-Peak Cell Delay Variation Identifier								
Acceptable Backward Peak-to-Peak Cell Delay Variation								7.1
Acceptable Backward Peak-to-Peak Cell Delay Variation(continue)								7.2
Acceptable Backward Peak-to-Peak Cell Delay Variation(continue)								7.3
1	0	0	1	0	1	1	0	8
Cumulative Forward Peak-to-Peak Cell Delay Variation Identifier								Note 1
Cumulative Forward Peak-to-Peak Cell Delay Variation								8.1
Cumulative Forward Peak-to-Peak Cell Delay Variation(continue)								8.2
Cumulative Forward Peak-to-Peak Cell Delay Variation(continue)								8.3

1	0	0	1	0	1	1	1	9
Cumulative Forward Peak-to-Peak Cell Delay Variation Identifier								Note 1
Cumulative Forward Peak-to-Peak Cell Delay Variation								9.1
Cumulative Forward Peak-to-Peak Cell Delay Variation(continue)								9.2
Cumulative Forward Peak-to-Peak Cell Delay Variation(continue)								9.3
1	0	0	1	0	1	1	1	10
Acceptable Forward Cell Loss Ratio Identifier								Note 2
Acceptable Forward Cell Loss Ratio								10.1
1	0	0	1	0	1	1	1	11
Acceptable Backward Cell Loss Ratio Identifier								Note 2
Acceptable Backward Cell Loss Ratio								11.1

Note 1 - If an acceptable forward and/or backward Peak-to-Peak CDV is included, then the corresponding cumulative forward and/or backward Peak-to-Peak CDV shall be included, respectively.

Note 2 - The acceptable forward and/or backward cell loss ratio specified is either for the CLP=0 traffic stream or for the CLP=0+1 traffic stream.

Coding Standard (octet 2)

Bits Meaning

7 6

1 1 ATM Forum Specific

Origin (octet 5)

Indicates the origin of this information element. If the origin is the calling party, then the called party can assume that the received cumulative values are end-to-end values. Otherwise, the received cumulative values do not represent end-to-end values.

Bits	Meaning
8765 4321	
0000 0000	Originating user
0000 0001	Intermediate network

Chapter IV defines the basic foundation for ATM-PNNI networks. The structure of the ATM-PNNI networks, routing overview, different messages and message format of the SETUP and CONNECT message. This information will be used in the chapter V for setting up the Virtual Path or Virtual Circuit. These VP or VC will be used to forward the data throughout the ATM-PNNI networks. The QoS classes will help to convert the MPLS traffic parameters into applicable ATM-PNNI traffic parameters. Extended QoS parameters will provide the bitwise information for encoding the Diff-Serv information into SET-UP message format.

CHAPTER V

Differentiated Service and Traffic Engineering Support for MPLS and ATM-PNNI Interoperability

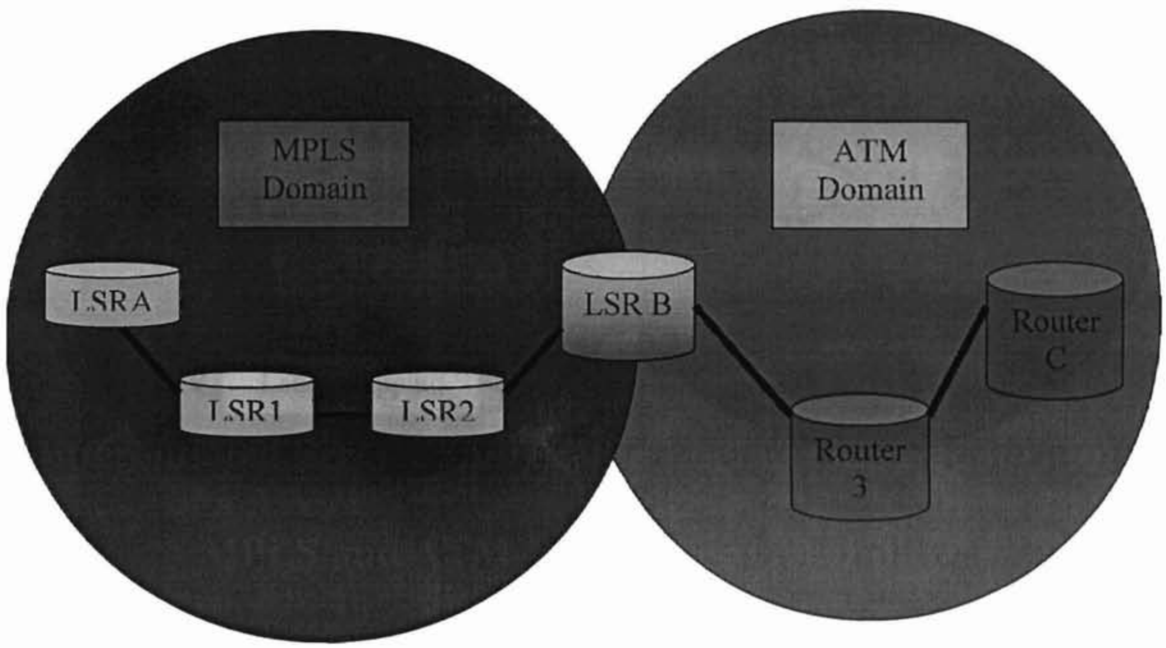

Figure 5-1 Representing MPLS and ATM-PNNI domain

5.1 MPLS →ATM-PNNI

As shown in the figure (5-1), the right side is ATM-PNNI domain and Left side is MPLS domain. In this case our source is in MPLS domain and destination in ATM-PNNI domain.

5.2 In MPLS domain, from Upstream LSR A to Downstream LSR B

We can have two type of communication mode.

1. **Demand Mode.**
2. **Unsolicited Mode**

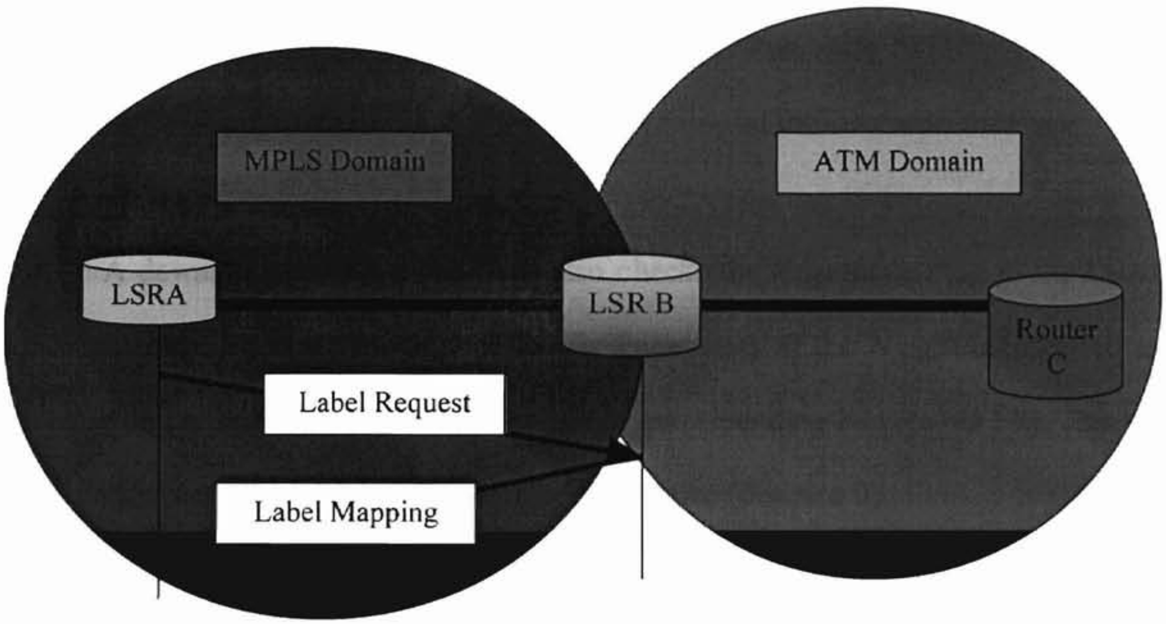

Figure 5-2 Representing Label Request Message and Label Mapping Massage in MPLS domain for QoS support.

5.2.1 Demand mode for CR-E-LSP:

As shown in the figure (5-2), ingress MPLS-LSR (A) sends Label Request message to ATM-MPLS Diff-Serv LSR (B) for requesting Label for CR-E-LSP. This

Label Request message contains desired Diff-Serv and TE parameters in terms of Diff-Serv TLV and Traffic TLV [10].

A downstream Diff-Serv LSR B checks the encoded Traffic Parameters TLV in the Label Request Message. If the value of PDR is less than the value of CDR then B have to send a Notification Message including the Status code "Traffic Parameters Unavailable" to the upstream LSR A from which it received the erroneous message.

A downstream Diff-Serv LSR B also checks the Negotiable Flag in the Label Request Message for negotiation of the Traffic Parameters. If the Weight is indicated as Negotiable in the Label Request Message by the corresponding Negotiable Flag then an LSR B may replace the Weight value with a lower value (down to 0).

After doing proper Negotiation, LSR A and B reserve the required Traffic Parameters resources for E-LSP. If not then, B sends Notification Message that contains the "Resource Unavailable" status code.

After receiving Label Request message, B also looks at the signaled EXP←→PHB mapping for proposed E-LSP in Diff-Serv TLV. This Label Request message with the Diff-Serv TLV contains one MAP entry for each EXP value to be supported on this E-LSP.

If an upstream Diff-Serv LSR A is using preconfigured EXP←→PHB mapping, then it does not include Diff-Serv TLV in Label Request message.

A downstream Diff-Serv LSR B, upon receiving a Label Request message with multiple Diff-Serv TLVs only considers the first one as meaningful. The LSR B ignores and does not forward the subsequent Diff-Serv TLVs.

If downstream Diff-Serv LSR B does not support the PHB encoded in one of the MAP entry, it sends Notification message, which includes the Status TLV with a Status Code of `Unsupported PHB'.

If downstream Diff-Serv LSR B determines that the signaled EXP←→PHB mapping is invalid in a Label Request message, it rejects the request by sending a Notification message, which includes the Status TLV with a Status Code of `Invalid EXP←→PHB Mapping'.

The signaled EXP←→PHB mapping in the Diff Serv TLV for an E-LSP is invalid in following cases:

- the MAPnb field is not within the range 1 to 8, or
- a given EXP value appears in more than one MAP entry, or
- the PHBID encoding is invalid.

Diff-Serv LSR B sends a Label Mapping message in response of a Label Request message for an E-LSP. This Label Mapping message does not include a Diff-Serv TLV.

If Diff-Serv LSR A receives a Label Mapping message in response to its Label Request message containing a Diff-Serv TLV, it rejects the label mapping by sending a Label Release message which includes the Label TLV and the Status TLV with a Status Code of `Unexpected Diff-Serv TLV'.

If an LSR A receives an incorrectly encoded Traffic Parameters TLV, which has the value of PDR is less than the value of CDR then it sends a Label Release message containing the Status code "Traffic Parameters Unavailable" to the LSR B from which it received the erroneous message.

If the negotiation flag was set in the label request message, then LSR A may receive possibly negotiated Traffic Parameters and Weight in the Label Mapping message differ than Label Request message.

At the end of Negotiation of the Traffic Parameters, Traffic Parameters and the Weight in a Label Mapping message must be forwarded unchanged.

Assuming the label set-up is successful, both the downstream and upstream LSRs:

- Update the Diff-Serv Context associated with the established LSPs in their ILM/FTN as specified in previous sections (incoming and outgoing label),

- Install the required Diff-Serv forwarding treatment (scheduling and dropping behavior) for this NHLFE (outgoing label).

Diff-Serv LSR B utilized the Traffic TLV and Diff-Serv TLV information as shown in section 3.3.3 and 3.3.2.

5.2.2 Unsolicited Mode for CR-E-LSP

This mode is very similar to Demand mode. The only difference in this mode is:

When allocating a label for CR-E-LSP by using a signaled EXP←→PHB mapping, a downstream Diff-Serv LSR B issues a Label Mapping message with the Diff-Serv TLV for an E-LSP which contains one MAP entry for each EXP value to be supported on this E-LSP.

An upstream Diff-Serv LSR A, upon receiving a Label Mapping message with multiple Diff-Serv TLVs only considers the first one as meaningful. The LSR A ignores and does not forward the subsequent Diff-Serv TLVs.

If upstream Diff-Serv LSR A does not support the PHB encoded in one of the MAP entry, it sends Notification message, which includes the Status TLV with a Status Code of `Unsupported PHB'.

If upstream Diff-Serv LSR A determines that the signaled EXP←→PHB mapping is invalid in a Label Mapping message, it rejects the request by sending a Notification message, which includes the Status TLV with a Status Code of `Invalid EXP←→PHB Mapping'.

The signaled EXP←→PHB mapping in the Diff Serv TLV for an E-LSP is invalid in following cases:

- The MAPnb field is not within the range 1 to 8, or
- A given EXP value appears in more than one MAP entry, or
- The PHBID encoding is invalid

Diff-Serv LSR B utilized the Traffic TLV and Diff-Serv TLV information as shown in section 3.3.3 and 3.3.2.

5.3 MPLS to ATM-PNNI domain from Diff-Serv MPLS-ATM-PNNI ROUTER B to Diff-Serv Support ATM Router C

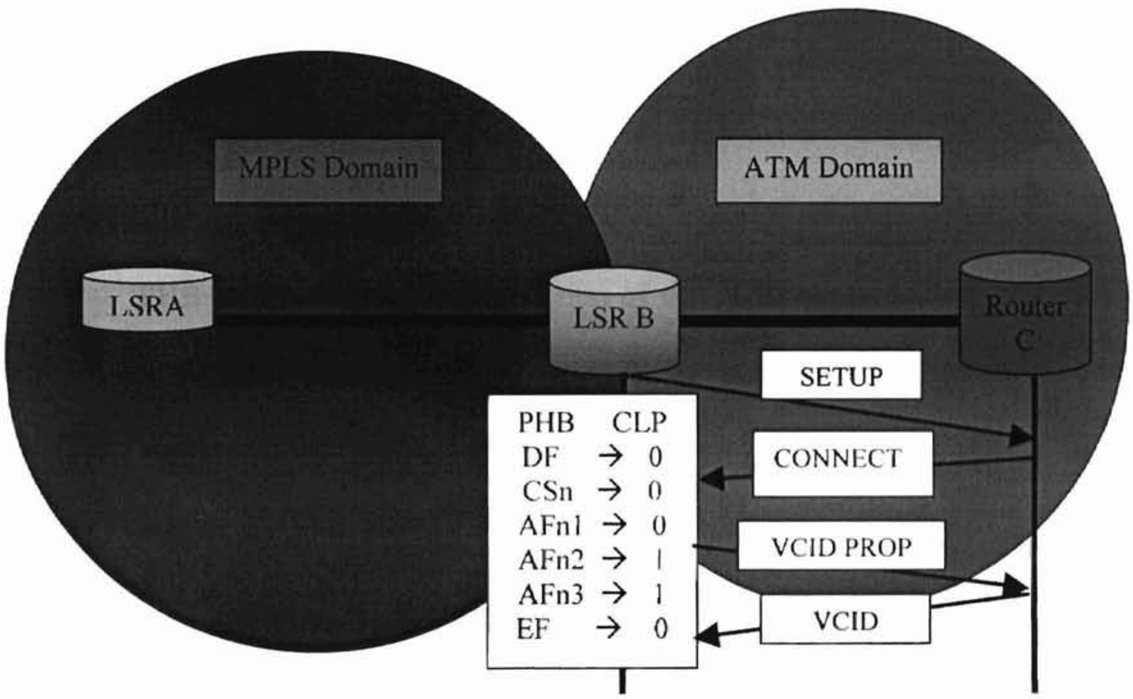

Figure 5-3 Representing SETUP, CONNECT, VPID/VCID Propose and VPID/VCID Acknowledge message in ATM-PNNI domain for allotting the VP/VC for the communication.

If we have CR-E-LSP for MPLS domain, then Diff-Serv MPLS-ATM-PNNI Router B should use pre-configured EXP←→PHB mapping over these interfaces. A Diff-Serv capable LSR B may support E-LSPs, which use signaled EXP←→PHB mapping over these interfaces.

Encoding Diff-Serv information into Encapsulation Layer:

If the E-LSP is egressing over an ATM interface, which is not label switching controlled, then "PHB→Encaps mappings" is carried out. That is also called as 'PHB→CLP mapping'.

5.3.1 'PHB→CLP mapping'

'PHB→CLP mapping' is a function of the PHBs supported on this LSP, and may use the relevant mapping entries for these PHBs for transforming this information in ATM-PNNI message format[10].

PHB		CLP Bit
DF	→	0
CSn	→	0
AFn1	→	0
AFn2	→	1
AFn3	→	1
EF	→	0

The Diff-Serv MPLS-ATM-PNNI Router B determines the value to be written in the CLP field of the ATM encapsulation header, by looking up the "outgoing PHB" in this PHB→CLP mapping table.

Table 5-1 MPLS to ATM-PNNI Traffic Engineering (TE) parameters conversion.

MPLS TE parameters	PDR	PBS	CDR	CBS	EBS	Service Frequency	Conditioning Action
ATM-CBR	PCR	CDVT	=PCR	=CDVT	0	VeryFrequent	drop>PCR
ATM-VBR.3(rt)	PCR	CDVT	SCR	MBS	0	Frequent	drop>PCR mark>SCR,MBS
ATM-VBR.3(nrt)	PCR	CDVT	SCR	MBS	0	Unspecified	drop>PCR mark>SCR,MBS
ATM-UBR	PCR	CDVT	-	-	0	Unspecified	drop>PCR
ATM-GFR.1	PCR	CDVT	MCR	MBS	0	Unspecified	drop>PCR
ATM-GFR.2	PCR	CDVT	MCR	MBS	0	Unspecified	drop>PCR mark>MCR,MFS

After determining the value for PCR, CDVT, SCR, MBS and CLP for ATM-PNNI domain, Diff-Serv MPLS-ATM-PNNI Router B convert all these Differentiated service and Traffic parameter information into the ATM-PNNI SET-UP message format [11].

Now this SET-UP message has fields like: AAL parameters, ABR additional parameters, ABR setup parameters, End-to-end transit delay, Extended QoS parameters, QoS parameter.

In response of SET-UP message Router C sends CONNECT message to indicate call/connection acceptance by Router C. Then ATM-LSR B sends VCID/VPID PROPOSE to the ATM Router C. In response of that message the ATM Router C sends VCID/VPID ACK. By these messages both edge Routers agree on particular Common VCID/VPID no. that way they allocate proper VC/VP for the communication.

Once the path is setup the data can be send.

5.4 ATM-PNNI→MPLS for E-LSP

ATM Router C send SETUP message to Diff-Serv MPLS-ATM-PNNI ROUTER B. This SET-UP message has fields like: AAL parameters, ABR additional parameters, ABR setup parameters, End-to-end transit delay, Extended QoS parameters, and QoS parameter. By using the inverse conversation of Table Diff-Serv MPLS-ATM-PNNI ROUTER B can get all the Traffic Parameters in terms of PDR, PBS, CDR, CBS and EBS. That can be directly used for Traffic Parameters TLV.

Same way by using `PHB→CLP mapping' we can have proper PHB information.

Once MPLS-ATM-PNNI ROUTER B has all the Diff-Serv and TE parameters. It can send Label Request message to downstream LSR A. In response of Label Request Message LSR A sends Label Mapping Message as shown above.

5.5 MPLS →ATM-PNNI for L-LSP

As shown in the figure (5-1), the right side is ATM-PNNI domain and Left side is MPLS domain. In this case our source is in MPLS domain and destination in ATM-PNNI domain.

5.5.1 In MPLS domain from Upstream LSR A to Downstream LSR B

5.5.1.1 Demand mode for CR-L-LSP:

Ingress MPLS-LSR (A) sends Label Request message to ATM-MPLS Diff-Serv LSR (B) for requesting Label for CR-E-LSP. This Label Request message contains desired Diff-Serv and TE parameters in terms of Diff-Serv TLV and Traffic TLV [10].

A downstream Diff-Serv LSR B checks the encoded Traffic Parameters TLV in the Label Request Message. If the value of PDR is less than the value of CDR then B have to send a Notification Message including the Status code "Traffic Parameters Unavailable" to the upstream LSR A from which it received the erroneous message.

A downstream Diff-Serv LSR B also checks the Negotiable Flag in the Label Request Message for negotiation of the Traffic Parameters. If the Weight is indicated as Negotiable in the Label Request Message by the corresponding Negotiable Flag then an LSR B may replace the Weight value with a lower value (down to 0).

After doing proper Negotiation, LSR A and B reserve the required Traffic Parameters resources for E-LSP. If not then, B sends Notification Message that contains the "Resource Unavailable" status code.

After receiving Label Request message, B also looks for proposed PSC in Diff-Serv TLV.

If a downstream Diff-Serv LSR B notices that the proposed PSC value is not supported by L-LSP, then it sends Notification message by rejecting the request with Status TLV with status code of "Unsupported PSC".

LSR B uses this PSC value with the PSC←→ PHB Mapping to decide the incoming and outgoing PHB for receiving and forwarding the data.

Diff-Serv LSR B sends a Label Mapping message in response of a Label Request message for an E-LSP. This Label Mapping message does not include a Diff-Serv TLV for demand mode as in the case of E-LSP.

If Diff-Serv LSR A receives a Label Mapping message in response to its Label Request message containing a Diff-Serv TLV, it rejects the label mapping by sending a Label Release message which includes the Label TLV and the Status TLV with a Status Code of `Unexpected Diff-Serv TLV'.

If an LSR A receives an incorrectly encoded Traffic Parameters TLV, which has the value of PDR is less than the value of CDR then it sends a Label Release message containing the Status code "Traffic Parameters Unavailable" to the LSR B from which it received the erroneous message.

If the negotiation flag was set in the label request message, then LSR A may receive possibly negotiated Traffic Parameters and Weight in the Label Mapping message differ than Label Request message.

At the end of Negotiation of the Traffic Parameters, Traffic Parameters and the Weight in a Label Mapping message must be forwarded unchanged.

Assuming the label set-up is successful, both the downstream and upstream LSRs:

- Update the Diff-Serv Context associated with the established LSPs in their ILM/FTN as specified in previous sections (incoming and outgoing label),
- Install the required Diff-Serv forwarding treatment (scheduling and dropping behavior) for this NHLFE (outgoing label).

Diff-Serv LSR B utilized the Traffic TLV and Diff-Serv TLV information as shown in section 3.3.3 and 3.3.2.

5.5.1.2 Unsolicited Mode for CR-L-LSP:

This mode is very similar to Demand mode. The only difference in this mode is:

A downstream Diff-Serv LSR B issues a Label Mapping message with the Diff-Serv TLV for an L-LSP, which contains the PHB Scheduling Class (PSC) to be supported on this L-LSP.

An upstream Diff-Serv LSR A, upon receiving a Label Mapping message with multiple Diff-Serv TLVs only considers the first one as meaningful. The LSR A ignores and does not forward the subsequent Diff-Serv TLVs.

If a downstream Diff-Serv LSR A notices that the proposed PSC value is not supported by L-LSP in the Label, then it sends a Notification message by rejecting the request with Status TLV with status code of "Unsupported PSC".

Diff-Serv LSR B utilized the Traffic TLV and Diff-Serv TLV information as shown in section 3.3.3 and 3.3.2.

5.6 MPLS to ATM-PNNI domain from Diff-Serv MPLS-ATM-PNNI ROUTER B to Diff-Serv Support ATM Router C:

If we have CR-L-LSP for MPLS domain, then Diff-Serv MPLS-ATM-PNNI Router B should use PSC←→PHB mapping over these interfaces. As shown in figure (5-3).

Encoding Diff-Serv information into Encapsulation Layer:

If the L-LSP is egressing over an ATM interface, which is not label switching controlled, then "PHB→Encaps mappings" is carried out. That is also called as 'PHB→CLP mapping'.

5.6.1 'PHB→CLP mapping'

'PHB→CLP mapping' is a function of the PHBs supported on this LSP, and may use the relevant mapping entries for these PHBs for transforming this information in ATM-PNNI message format.

PHB		CLP Bit
DF	→	0
CSn	→	0
AFn1	→	0
AFn2	→	1
AFn3	→	1
EF	→	0

The Diff-Serv MPLS-ATM-PNNI Router B determines the value to be written in the CLP field of the ATM encapsulation header, by looking up the "outgoing PHB" in this PHB→CLP mapping table[10].

Table 5-2 MPLS to ATM-PNNI TE parameters conversion.

MPLS TE PARAMETERS	PDR	PBS	CDR	CBS	EBS	Service Frequency	Conditioning Action
ATM-CBR	PCR	CDVT	=PCR	=CDVT	0	VeryFrequent	drop>PCR
ATM-VBR.3(rt)	PCR	CDVT	SCR	MBS	0	Frequent	drop>PCR mark>SCR,MBS
ATM-VBR.3(nrt)	PCR	CDVT	SCR	MBS	0	Unspecified	drop>PCR mark>SCR,MBS
ATM-UBR	PCR	CDVT	-	-	0	Unspecified	drop>PCR
ATM-GFR.1	PCR	CDVT	MCR	MBS	0	Unspecified	drop>PCR
ATM-GFR.2	PCR	CDVT	MCR	MBS	0	Unspecified	drop>PCR mark>MCR,MFS

After determining the value for PCR, CDVT, SCR, MBS and CLP for ATM-PNNI domain, Diff-Serv MPLS-ATM-PNNI Router B convert all these Differentiated service and Traffic parameter information into the ATM-PNNI SET-UP message format [11].

Now this SET-UP message has fields like: AAL parameters, ABR additional parameters, ABR setup parameters, End-to-end transit delay, Extended QoS parameters and QoS parameter.

In response of SET-UP message Router C sends CONNECT message to indicate call/connection acceptance by Router C. Then ATM-LSR B sends VCID/VPID PROPOSE to the ATM Router C. In response of that message the ATM Router C sends

VCID/VPID ACK. By these messages both edge Routers agree on particular Common VCID/VPID no. That way they allocate proper VC/VP for the communication.

Once the path is setup the data can be send.

5.7 ATM-PNNI→MPLS for L-LSP

ATM Router C send SETUP message to Diff-Serv MPLS-ATM-PNNI ROUTER B. This SET-UP message has fields like: AAL parameters, ABR additional parameters, ABR setup parameters, End-to-end transit delay, Extended QoS parameters, and QoS parameter. By using the inverse conversation of Table Diff-Serv MPLS-ATM-PNNI ROUTER B can get all the Traffic Parameters in terms of PDR, PBS, CDR, CBS and EBS. That can be directly used for Traffic Parameters TLV.

Now, LSR B uses the 'CLP →PHB mapping from the available information from the Router C.

5.7.1 `CLP→PHB mapping'

Now, LSR B uses the 'CLP →PHB mapping from the available information from the Router C to decide the proper PSC for the L-LSP.

CLP Bit	PSC		PHB
0	DF	→	DF
0	CSn	→	CSn
0	AFn	→	AFn1
1	AFn	→	AFn2
0	EF	→	EF

Once MPLS-ATM-PNNI ROUTER B has all the Diff-Serv and TE parameters, it can send Label Request message to downstream LSR A. In response of Label Request Message LSR A sends Label Mapping Message as shown above[10].

Summary

This chapter will define the unique solution to set-up the LSP (L-LSP or E-LSP) within the MPLS domain with the support of Diff-Serv. For that we have used the concept of LSP form chapter II, operation of LSR from chapter III and ATM-PNNI messages from chapter IV.

CHAPTER VI

Observation & Results

As Internet is becoming widely spread communication medium in public networks, the users are demanding for high-speed services with Class of Services (CoS). To achieve this task MPLS has been introduced, which can provide the combine features of IP and ATM, the Data Link Layer switching. In effort of integration of the MPLS with ATM-PNNI can have all the features combined to provide the QoS and TE support for the traffic.

Since the QoS & TE are becoming very important issues for scalable multi-class services in IP networks. In the existing Diff-Serv supporting network, like ATM-PNNI or Frame-relay, MPLS Traffic Engineering mechanisms should not be used directly to provide the Diff-Serv. There should be backward compatibility issues to make it work through these different domain of public networks.

QoS performs service differentiation and integration at every hop of the network; TE handles the proper distribution of aggregate traffic load across the set of the resources. That includes the Constraint Based Routing and Admission Control with some set of BAs. But, they should be independent of each other.

By using the mechanism discussed in this paper, the proper mapping of the traffic line in a given class on a separate LSP, which helps that traffic line to utilize the available resources on both shortest path and non-shortest path and follow the TE constraints.

To achieve QoS and TE requirement, this mechanism directly impacts the scalability.

The basic need of QoS and TE supporting network [18]:

- It should not cause the interoperability issues with the existing TE mechanism. Means network that is not supporting the QoS and TE should not be impacted in any way.
- The mechanism might want to provide the required level of granularity and scope (e.g. only for the number of classes required in the considered network).
- The main requirement to support the Diff-Serv and TE is to be able to enforce the different bandwidth constraints for different class.
- Priority requirement:
    1. If sometimes-lower priority class is using the resources of the higher prority class, when required higher priority class can reclaims its resources.
    2. Lower priority class should not be completely starved by higher priority classes.
    3. Higher priority classes should not be routed away from the shortest path because of lower priority class.

By using the discussed mechanism for interfacing MPLS with ATM-PNNI, one can achieve the above requirements for Diff-Serv support. The LSR plays the key role for proper mapping of incoming traffic into corresponding LSP. For constraint based routing, LSR uses the different BAs and their OAs to transport the packets. The proper determination of BAs at LSR based on the Diff-Serv Code point in the packet header.

Moreover, the benefits of MPLS can always be achieved within the MPLS networks. Those are following:

- MPLS integrates IP routing capability with ATM functionality rather than using IP over ATM. So MPLS doesn't require ATM addressing and routing techniques.
- In existing ATM under IP technique, one can set up Permanent Virtual Circuits (PVCs) and Switched Virtual Circuits (SVCs) in between the routers over ATM domain. If one ATM link fails, it makes several router-to-router links failure. Failure of one link makes more processing due to large amount of traffic through the routers. MPLS can do it with higher reliability easily.
- MPLS utilized the routing weights technique to share the load in MPLS domain that prevents the "HOT SPOTs" in the public networks.
- MPLS uses ATM queuing and buffer capabilities. To provide different Service Level Agreements with those SLAs it defines Classes of services for ATM hardware. MPLS uses those entire CoS with direct support of IP precedence, which is defined in ATM Forum, without complex modifications.
- In contrast of overlaying IP over ATM hardware, MPLS has other advantage like IP multicast. MPLS also support for RSVP.

- MPLS domain makes VPN services extremely scalable and easily manageable. MPLS provides controllable tunneling mechanism for VPN support.
- With the Hierarchical Routing knowledge of MPLS, one can access the Internet routing table. One can eliminate or reduce the transit traffic entering to Autonomous System with the help of this routing table.
- MPLS supports IP traffic engineering parameters like traffic type, time jitter, time delay, traffic load and destination etc for Constraint-based Routing. By using these parameters one can divide the traffic from over-loaded route to under-loaded to eliminate the Hotspot.
- MPLS enables us to utilize the network resources efficiently.
- The applications like voice/video on IP require the Delay variation and QoS constraints. MPLS support of QoS makes it more suitable for such real time applications.
- MPLS control protocol integrates L2 and L3 together, which makes it ultra-fast forwarding technology.

CHAPTER VII

CONCLUSION

The available publications like [16] and [17] describe the way in which the Diff-Serv LSR uses the Diff-Serv & Traffic Engineering TLV to compute the Interarrival Jitter and Cell/Packet Loss Ratio. Publication [10] defines the steps to use Diff-Serv & TE TLV information to forward the label or data. None of the published paper exactly talks about the novel details "To setup the LSP in MPLS domain to provide the controllability for QoS."

This paper also describes how we can transfer the Diff-Serv information to interoperate the MPLS with ATM-PNNI domain. We then described the procedures, which should be followed to support the Diff-Serv for transferring the data from MPLS domain to ATM-PNNI domain.

To accomplish the transition from currently deployed Network technology ATM-PNNI to MPLS with QoS and TE support, one can use Traffic parameter TLV and Diff-Serv TLV for CR-LDP for MPLS domain to support real time video or voice applications like Near VoD, interactive TV, Videogames etc. To transfer this information from one domain to other, the LSR uses the EXP-to-PHB mapping and PHB-to-EXP mapping (EXP←→PHB mapping). With the ATM traffic management mechanisms, which are already there and implemented in ATM switches, we can provide all the functionality and flexibility requested. QoS and TE support (Diff-Serv Support) with MPLS and ATM-PNNI domain gives us Flexibility, Extendibility, Scalability and Backward compatibility.

CHAPTER VIII

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