1

MULTI-PROTOCOL LABEL SWITCHING

1.1 INTRODUCTION

It is estimated that in the near future, data will account for 80 % of all traffic carried by telecommunications networks. Therefore, the past concept of telephone networks which also carry data will be replaced by the concept of data networks that also carry voice. Lately the telecommunication industry has been highly focused on the leap to IP for telecommunication services. It is foreseen that Multiprotocol Label Switching (MPLS) will be chosen as the bearer of IP in future large backbone networks.

Multi-Protocol Label Switching (MPLS) [RVC01],[CDF$^+$99] has recently been accepted as a new approach for integrating layer 3 routing (IP) with layer 2 switching technology (Asynchronous Transfer Mode (ATM), Frame relay (FR) and the extension Generalized MPLS (GMPLS) for optical networks). It tries to provide the best of both worlds: the efficiency and simplicity of routing together with the high speed of switching. For this reason MPLS is considered to be a promising technology that addresses the needs of future IP-based networks. It enhances the services that can be provided by IP networks, offering scope for Traffic Engineering (TE), guaranteed Quality of Service (QoS), Virtual Private Networks (VPNs), etc. MPLS does not replace IP routing, but works along with existing and future routing technologies to provide very high-speed data forwarding between Label-Switched Routers(LSRs) together with QoS provision.

1.2 BACKGROUND

One challenge in current network research is how to effectively transport IP traffic over any network layer technology (ATM, FR, Ethernet, Point-to-Point). IP was independently developed on the basis of a connectionless model. In a connectionless network layer protocol when a packet travels from one router to the next, each router looks at the packet header to take the decision to forward the packet to the next corresponding hop according to a network layer routing algorithm based on the longest prefix match forwarding principle. Routers forward each IP packet independently on a hop-by-hop basis. Therefore, IP traffic is usually switched using packet software-forwarding technology, which has a limited forwarding capacity.

On the other hand, connection-oriented networks (ATM, FR) establish a virtual connection from the source to the destination (end-to-end) before forwarding the packets. That is, a connection must be established between two parties before they can send data to each other. Once the connection is set up, all data between them is sent along the connection path.

To relate the ATM and the IP protocol layers, two models have been proposed: the overlay model and the integrated model.

1.2.1 Overlay model

The overlay model considers ATM as a data link layer protocol on top of which IP runs. In the overlay model the ATM network has its own addressing scheme and routing protocol. The ATM addressing space is not logically coupled with the IP addressing space, in consequence direct mapping between them is not possible. Each end system will typically have an ATM address and an unrelated IP address. Since there is no mapping between the two addresses, the only way to resolve one from other is through some address resolution protocol. This involves running two control planes: first ATM Forum signaling and routing and then on top of that, IP routing and address resolution.

Substantial research has been carried out and various standards have been ratified by IETF and the ATM Forum addressing the mapping of IP and ATM, such as: Classical IP over ATM [LH98], Next Hop Resolution Protocol(NHRP)[LKP+98], LAN Emulation(LANE) [lan95], Multi-Protocol Over ATM(MPOA) [mpo97], etc. Furthermore, a rather complex signaling protocol has been developed so that ATM networks can be deployed in the wide area, Private Network-to-Network Interface (P-NNI) [pnn96].

Mapping between IP and ATM involves considerable complexity. Most of the above approaches servers (e.g., ATMARP, MARS, NHRS, and BUS) to handle one of the mapping functions, along with a set of protocols necessary to interact with the server. This server solution to map IP over ATM represents at the same time a single point of failure, and thus there is a desire to implement redundant servers, which then require a synchronization protocol to keep them consistent with each other. In addition to this, none of the above approaches exploit the QoS potential of layer 2 switches, i.e., the connection continues to be best-effort.

1.2.2 Integrated Model

The need for an improved set of protocols for ATM switches than those defined by the ATM Forum and the ITU has been addressed by various label switching approaches. These approaches are in fact attempts to define a set of protocols which can control an ATM switch in such a way that the switch naturally forwards IP packets without the help of servers mapping between IP and ATM.

Several label switching approaches have been proposed toward the integration of IP and ATM, supporting both layer 3 IP routing (software forwarding) and layer 2 ATM hardware switching [DDR98]. Under such names as Cell Switching Router (CSR)[KNE97][KNE96][NKS+97][KNME97], IP switching [NLM96][NEH+96a] [NEH+96b][NEH+98], Tag Switching [DDR98][RDK+97], and Aggregate Route-based IP Switching(ARIS) [AFBW97][FA97], layer 3 routing and label binding/swapping are used as a substitute for layer 2 ATM routing and signaling for the ATM hardware-switched connection setup. These four approaches to label switching are the founding contributors of MPLS technology.

Although label switching tries to solve a wider range of problems than just the integration of IP and ATM, the difficulties associated with mapping between IP and ATM protocol models was a significant driver for the development of label-switching technology. Therefore, these early developments were meant to resolve the challenges presented by overlay models (IP over ATM). All these tagging and label swapping approaches provide data forwarding using labels.

In the evolution of MPLS there are perhaps two key ideas. The first is that there is no reason that an ATM switch can't have a router inside it (or a router have ATM switch functionality inside it). The second is that once the router and ATM switch are integrated, dynamic IP routing can be used to trigger virtual circuit (VC) or path setup. Instead of using management software or manual configuration to drive circuit setup, dynamic IP routing might actually drive the creation of circuits or Label Switch Path (LSP) establishment.

Among the many positive attributes that MPLS brings to internetworking is the ability to provide connection-oriented services to inherently connectionless IP networks. The label switched path (LSP) is the establishment of a unidirectional end-to-end path forwarding data based on fixed size labels.

1.3 MPLS ARCHITECTURE

The basis of MPLS operation is the classification and identification of IP packets at the ingress node with a short, fixed-length, and locally significant identifier called a label, and forwarding the packets to a switch or router that is modified to operate with such labels. The modified routers and switches use only these labels to switch or forward the packets through the network and do not use the network layer addresses.

1.3.1 Separation of Control and Data Planes

A key concept in MPLS is the separation of the IP router's functions into two parts: forwarding (data) and control [CO99]. The separation of the two components enables each to be developed and modified independently.

The original hop-by-hop forwarding architecture has remained unchanged since the invention of Internet architecture; the different forwarding architecture used by connection-oriented link layer technologies does not offer the possibility of a true end-to-end change in the overall forwarding architecture. For that reason, the most important change that MPLS makes to the Internet architecture is to the forwarding architecture. It should be noted that MPLS is not a routing protocol but is a fast forwarding mechanism that is designed to work with existing Internet routing protocols, such as Open Shortest Path First(OSPF) [Moy98], Intermediate System-to-Intermediate System (IS-IS) [Ora90], or the Border Gateway Protocol(BGP) [RL95].

The control plane consists of network layer routing protocols to distribute routing information between routers, and label binding procedures for converting this routing information into the forwarding table needed for label switching. Some of the functions accomplished by the control plane are to disseminate decision-making information, establish paths and maintain established paths through the MPLS network. The component parts of the control plane and the data plane are illustrated in Figure 1.1.

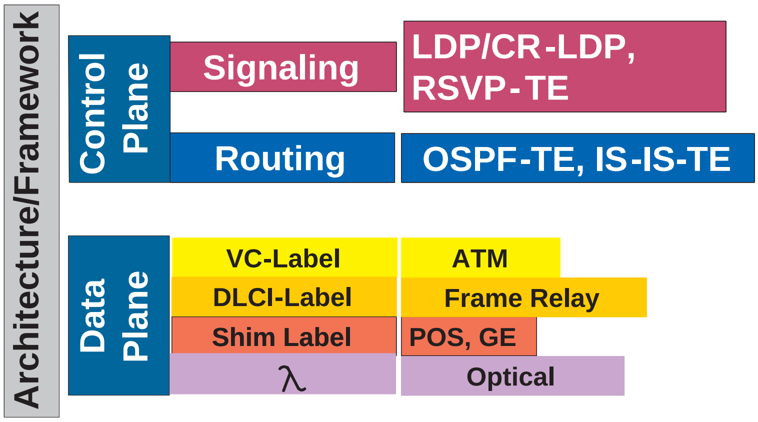

Figure 1.1 Control and Data plane components

The data plane (forwarding plane) is responsible for relaying data packets between routers (LSRs) using label swapping. In other words, a tunnel is created below the IP layer carrying client data. The concept of a tunnel (LSP tunnel) is key because it means the forwarding process is not IP based but label based. Moreover, classification at the ingress, or entry point to the MPLS network, is not based solely on the IP header information, but applies flexible criteria to classify the incoming packets.

1.3.2 Forward Equivalent Class (FEC)

Forward Equivalent Class (FEC) is a set of packets that are treated identically by an LSR. Thus, a FEC is a group of IP packets that are forwarded over the same LSP and treated in the same manner and can be mapped to a single label by an LSR even if the packets differ in their network layer header information. Figure 1.2 shows this behavior. The label minimizes essential information about the packet. This might include destination, precedence, QoS information, and even the entire route for the packet as chosen by the ingress LSR based on administrative policies. A key result of this arrangement is that forwarding decisions based on some or all of these different sources of information can be achieved by means of a single table lookup from a fixed-length label.

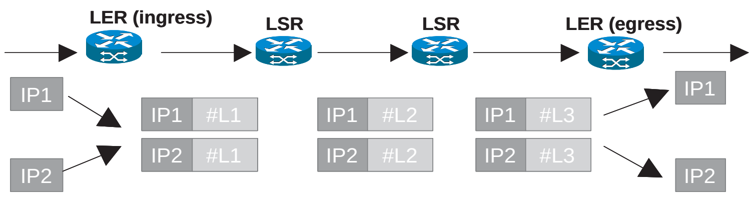

Figure 1.2 Forward Equivalent Class (FEC)

This flexibility is one of the key elements that make MPLS so useful. Moreover, assigning a single label to different flows with the same FEC has advantages derived from "flow aggregation". For example, a set of distinct address prefixes (FECs) might all have the same egress node, and label swapping might be used only to get the traffic to the egress node. In this case, within the MPLS domain, the union of those FECs is itself a FEC [RVC01]. Flow aggregation reduces the number of labels which are needed to handle a particular set of packets, and also reduces the amount of label distribution control traffic needed. This improves scalability and reduces the need for CPU resources.

1.3.3 Label

A label called a "shim label", or an MPLS "shim" header is a short, fixed-length, locally significant FEC identifier. Although the information on the network layer header is consulted for label assignment, the label does not directly encode any information from the network layer header like source or destination addresses [DR00]. The labels are locally significant only, meaning that the label is only useful and relevant on a single link, between adjacent LSRs. Figure 1.3 presents the fields of an MPLS “shim” header.

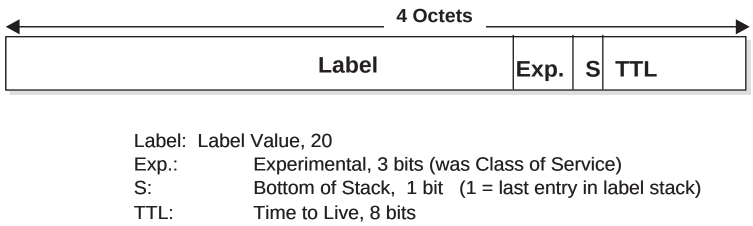

Figure 1.3 MPLS “shim” header format

In MPLS the assignment of a particular packet to a particular flow is done just once, as the packet enters the network. The flow (Forward Equivalence Class) which the packet is assigned to is encoded with a short fixed length value known as a “label” [RTF+01] Figure 1.3. When a packet is forwarded to the next hop, this label is sent along with it, that is, the packets are “labeled”. At subsequent hops there is no further analysis of the packet’s network layer header. The label itself is used as hop index. This assignment eliminates the need to perform the longest prefix-match computation for each packet at each hop, as shown in Figure 1.4. In this way the computation can be performed just once, as shown in Figure 1.5.

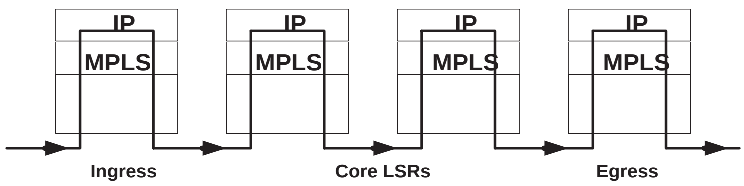

Figure 1.4 IP Forwarding: all LSRs extract information from layer 3 and forward the packets

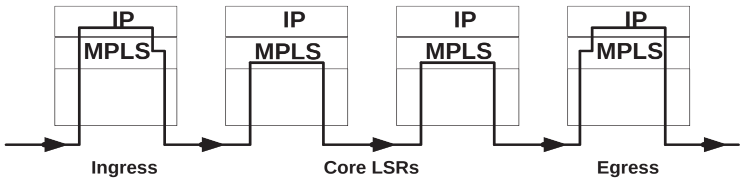

Figure 1.5 MPLS Forwarding: Ingress LSR extracts layer 3 information, assigns packet to FEC, pushes a label and forwards the packet. Core LSRs use label forwarding. Egress LSR pops the label, extracts layer 3 information and forwards the packet accordingly

1.3.4 Label Encapsulations

MPLS is multi protocol because is intended to run over multiple data link layers such as: ATM, Frame Relay, PPP, Ethernet, etc. It is label switching because it is an encapsulation protocol. The label encapsulation in MPLS is specified over various media type [DR00]. The top label on the stack may use the existing formats, lower label(s) use a new shim labels format. For IP-based MPLS, shim labels are inserted prior to the IP header. For ATM, the VPI/VCI addressing is the label. For Frame Relay, the DLCI is the label. Regardless of the technology, if the packet needs additional labels it uses a stack of shim labels. Figure 1.6 illustrates the label encapsulation in MPLS architecture.

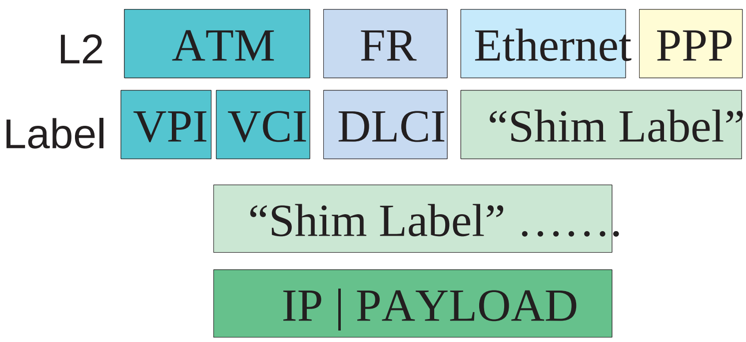

Figure 1.6 Label encapsulation

1.3.5 Label Swapping

Label Swapping is a set of procedures where an LSR looks at the label at the top of the label stack and uses the Incoming Label Map (ILM) to map this label to Next Hop Label Forwarding Entry (NHLFE). Using the information in the NHLFE, The LSR determines where to forward the packet, and performs an operation on the packet's label stack. Finally, it encodes the new label stack into the packet, and forwards the result. This concept is applicable in the conversion process of unlabeled packets to labeled packets in the ingress LSR, because it examines the IP header, consults the NHLFE for the appropriate FEC (FTN), encodes a new label stack into the packet and forwards it.

1.3.6 Label Stacking

A label stack is a sequence of labels on the packet organized as a last-in, first-out stack. A label stack enables a packet to carry information about more than one FEC which allows it to traverse different MPLS domains or LSP segments within a domain using the corresponding LSPs along the end-to-end path. Note that label processing is always based on the top label, without concern that some number of other labels may have been "above it" in the past, or that some number of other labels may be below it at present. The bottom of stack bit "S" in the shim header (see Figure 1.3) indicates the last stack level. The label stack is a key concept used to establish LSP Tunnels and the MPLS Hierarchy. Figure 1.7 illustrates the tunnelling function of MPLS using label stacks.

1.3.7 Label Switch Router (LSR)

A Label Switch Router(LSR) is a device that is capable of forwarding packets at layer 3 and forwarding frames that encapsulate the packet at layer 2. It is both a router and a layer 2 switch that is capable of forwarding packets to and from an MPLS domain. The edge LSRs are also known as Label Edge Routers (LERs).

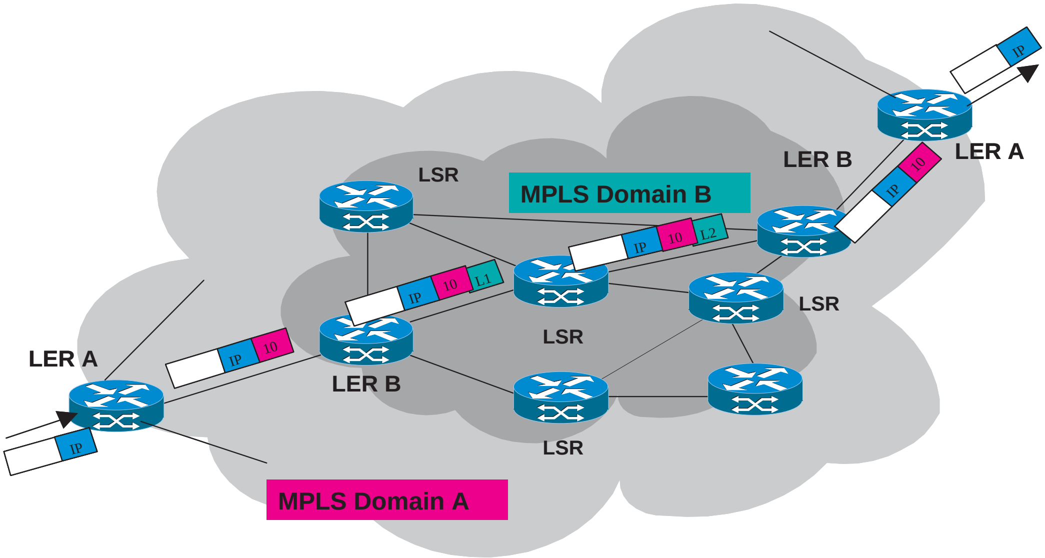

Figure 1.7 Label Stack. LERs A are for MPLS domain A and LERs B are for MPLS domain B

The ingress LSR pushes the label on top of the IP packet and forwards the packet to the next hop. In this phase as the incoming packet is not labeled, the FEC-to-NHLFE (FTN) map module is used.

Each intermediate/transit LSR examines only the label in the received packet, replaces it with the outgoing label present in the label information based forwarding table (LIB) and forwards the packet through the specified port. This phase uses the incoming label map (ILM) and next-hop label forwarding entry (NHLFE) modules in the MPLS architecture.

When the packet reaches the egress LSR, the label is popped and the packet is delivered using the traditional network layer routing module. All the above descriptions are illustrated in Figure 1.8.

If the egress LSR is not capable of handling MPLS traffic, or for the practical advantage of avoiding two lookup times that the egress LSR requires to forward the packet,

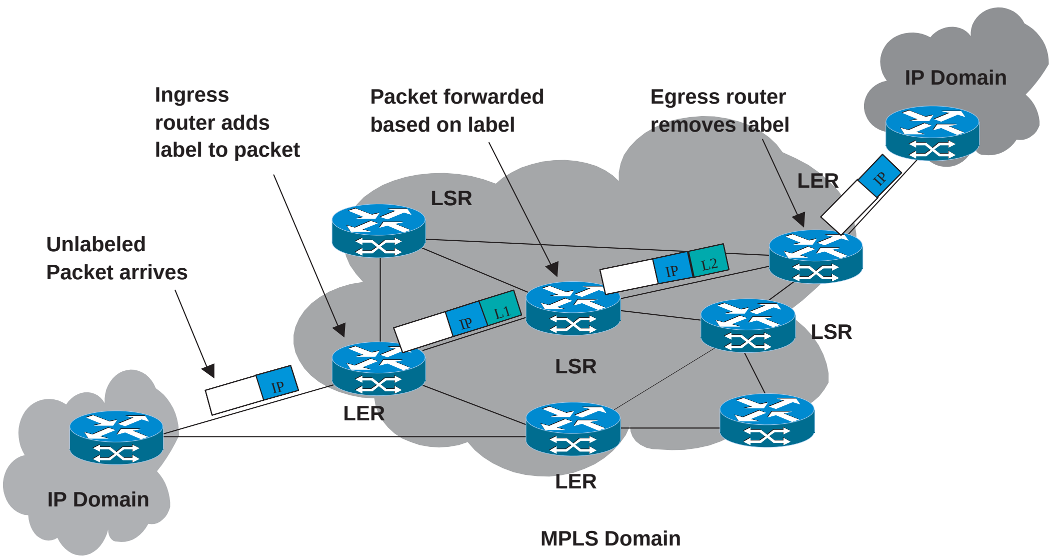

Figure 1.8 MPLS Architecture

the penultimate hop popping method is used. In this method, the LSR whose next hop is the egress LSR, will handle the label stripping process instead of the egress LSR.

1.3.8 Label Switched Path (LSP)

A Label Switched Path (LSP) is an ingress-to-egress switched path built by MPLS capable nodes which an IP packet follows through the network and which is defined by the label (Figure 1.9). The labels may also be stacked, allowing a tunnelling and nesting of LSPs [RVC01] [RTF$^+$01]. An LSP is similar to ATM and FR circuit switched paths, except that it is not dependent on a particular Layer 2 technology.

Label switching relies on the set up of switched paths through the network. The path that data follows through a network is defined by the transition of the label values using a label swapping procedure at each LSR along the LSP. Establishing an LSP involves configuring each intermediate LSR to map a particular input label and

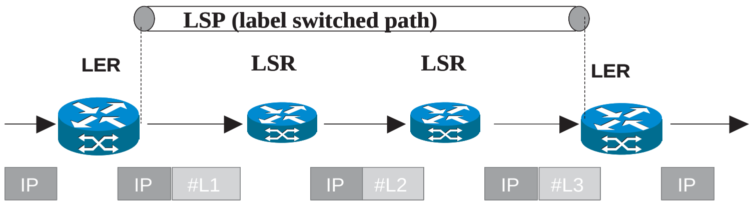

Figure 1.9 Label Switched Path (LSP)

interface to the corresponding output label and interface (label swap). This mapping is stored in the label information based forwarding table (LIB).

There are two kinds of LSP depending on the method used for determining the route: hop-by-hop routed LSPs when the label distribution protocol (LDP) [ADF+01] is used, and explicit routed if the path should take into account certain constraints like available bandwidth, QoS guarantees, and administrative policies; explicit routing uses the constraint routed label distribution protocol (CR-LDP) [JAC+02] or the Resource Reservation Protocol with traffic engineering extensions (RSVP-TE) [ABG+01] as signaling protocols.

1.4 LABEL DISTRIBUTION PROTOCOL

In MPLS two adjacent Label Switching Routers (LSRs) must agree on the meaning of labels used to forward traffic between them and through them. The label distribution protocol (LDP) is a protocol defined by IETF MPLS WG [ADF+01] for distributing labels in MPLS networks. LDP is a set of procedures and messages by which LSRs establish Label Switched Paths(LSPs) through a network by mapping network layer routing information directly to data link layer switched paths, as shown in Figure 1.10.

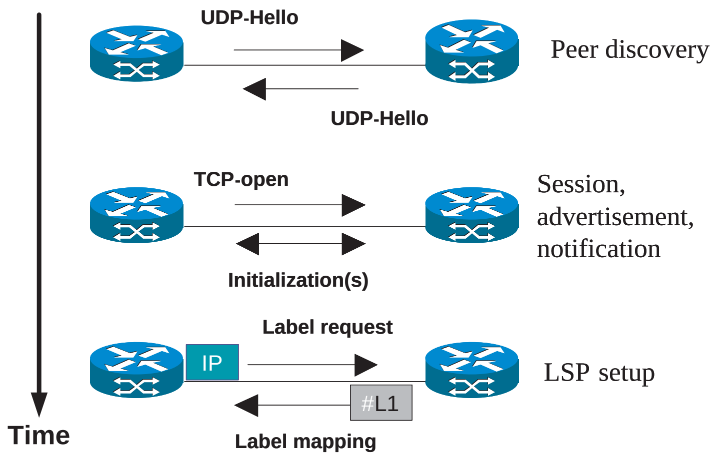

Figure 1.10 Label Distribution Protocol (LDP)

1.5 LABEL DISTRIBUTION MODES

In the MPLS architecture, the decision to bind a label to a FEC is made by the LSR which is downstream with respect to that binding. The downstream LSR informs to the upstream LSR of the label that it has assigned to a particular FEC. Thus labels are "downstream assigned" [RVC01].

The MPLS architecture defines two downstream assignments of label distribution modes for label mapping in LSRs: they are Downstream-on-Demand label distribution mode and Unsolicited Downstream label distribution mode.

1.5.1 Downstream-on-Demand

The MPLS architecture allows an LSR to explicitly request, from its next hop for a particular FEC, a label binding for that FEC. This is known as the "Downstream-on-Demand" label distribution mode, where the upstream LSR is responsible for requesting a label for binding. Figure 1.11 shows this process.

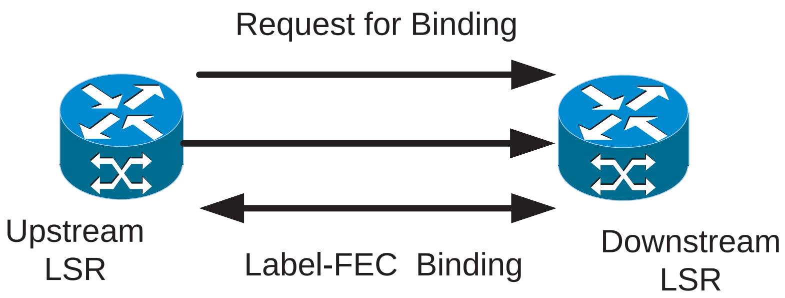

Figure 1.11 Downstream-on-Demand Label Advertisement

1.5.2 Unsolicited Downstream

The MPLS architecture also allows an LSR to distribute label bindings to LSRs that have not explicitly requested them. This is known as the "Unsolicited Downstream" label distribution mode, where the downstream LSR is responsible for advertising a label mapping to upstream LSRs. Figure 1.12 illustrates a downstream LSR delivering a label-FEC binding to an upstream LSR without having been requested for it.

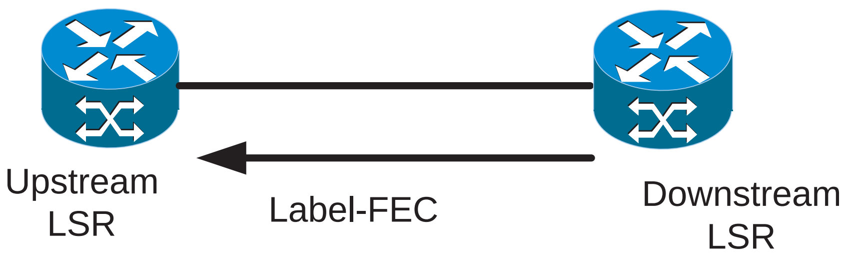

Figure 1.12 Unsolicited Downstream Label Advertisement

1.6 LSP CONTROL MODES

There are two label distribution control modes defined in the MPLS architecture to create (establish) an LSP. They are Independent Label Distribution Mode and Ordered Label Distribution Mode.

1.6.1 Independent Label Distribution control

In the independent label distribution control, each LSR makes an independent decision to bind a label to a particular FEC and to distribute that binding to its label distribution peers (i.e., its neighbors). This corresponds to the way that conventional IP datagram routing works; each node makes an independent decision as to how to treat each packet.

If the independent downstream-on-demand mode is used, the LSR may reply to a request for label binding without waiting to receive the corresponding label binding from the next hop. When the independent unsolicited downstream mode is used, an LSR advertises a label binding for a particular FEC to its label distribution peers whenever the label is ready for that FEC.

1.6.2 Ordered Label Distribution Control

In ordered label distribution control, an LSR only binds a label to a particular FEC in response to a label binding request. The egress LSR sends a label for that FEC directly since it is the last node in the MPLS domain . If the LSR is an intermediate LSR it must have already received a label binding for that FEC from its next hop before it sends its label binding. In this control mode, except the egress LSR, before an LSR can send a label to upstream LSRs, it must wait to receive the label for its request from a downstream LSR.

1.7 LABEL RETENTION MODES

There are two modes to retain labels in an LSR defined in the MPLS architecture. These are Liberal and Conservative label retention modes. These modes specify whether an LSR maintains a label binding or not for a FEC learned from a neighbor that is not its next hop for this FEC according to the routing.

1.7.1 Liberal Label Retention Mode

In liberal label retention mode, every label binding received from label distribution peers in an LSR is retained regardless of whether the LSR is the next hop for the label binding (i.e., whether they are used for packet forwarding or not).

The unsolicited downstream label advertisement mode is an example of when all received labels are retained and maintained by the upstream LSR, as illustrated in Figure 1.13.

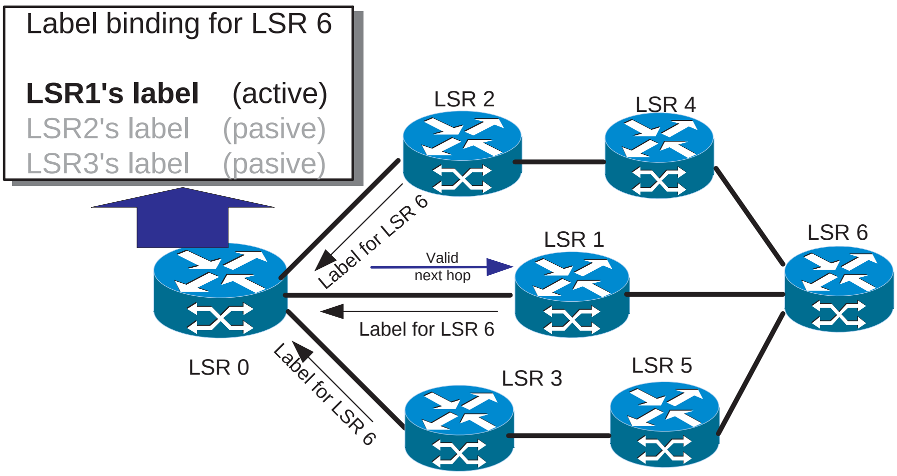

Figure 1.13 Liberal Label Retention Mode

The main advantage of the liberal label retention mode is that the response to routing changes may be fast because the LSR already has spare labels in its LIB. The disadvantage is that it maintains and distributes unnecessary labels.

1.7.2 Conservative Label Retention Mode

In conservative label retention mode the advertised label bindings are retained only if they will be used to forward packets (i.e., if they are received from a valid next hop according the routing), as shown in Figure 1.14. Note that Downstream-on-Demand forces in some way the use of conservative retention mode, rather than the liberal.

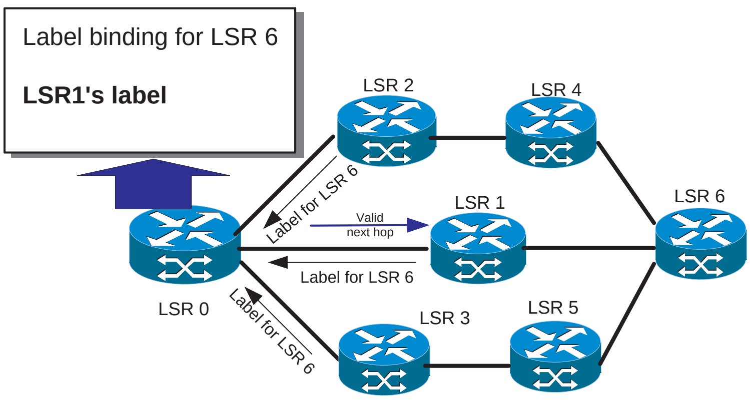

Figure 1.14 Conservative Label Retention Mode

The main advantage of the conservative mode is that only the labels that are required for forwarding of data are retained and maintained. This is very important for scalability in LSRs with limited label space. The disadvantage is well seen when rerouting is needed. In this case a new label must be obtained from the new next hop before labeled packets can be forwarded.

1.8 CONTROL PLANE

1.8.1 Information Dissemination

The link state protocols, specifically OSPF and IS-IS, provide the link state information that details the entire underlying network. This information is crucial to path selection, path establishment and maintenance functions. Further, both OSPF and IS-IS protocols have been extended to include resource information about all links in the specific area. Through these extensions MPLS traffic engineering becomes possible.

1.8.2 Path Selection

The control plane determines the best path through a network using either a hop-by-hop or an explicit route methodology. The hop-by-hop method allows the selection to follow the normal underlying IGP best path. Each node in the path is responsible for determining the best next hop based on the link state database. Alternatively, an explicit route is a path through the network that is specified by the ingress LSR. The explicitly routed path has administratively configured criteria or policies to influence the path selection through the underlying network.

1.8.3 Path Establishment

Once the path has been determined, a signaling protocol (LDP, CR-LDP or RSVP) is used to inform all the routers in the path that a new label switched path (LSP) is required. The signaling protocol is responsible for indicating the specifications of the path, including the session id, resource reservations, and the like, to all other routers in the path. This process also includes the label mapping request for all data that will use the LSP. Following the successful establishment of the path, the signaling protocol is responsible for ensuring the integrity of the peering session.

1.9 DATA PLANE

1.9.1 Packet Forwarding

The data flow into an MPLS network occurs at the ingress LSR, commonly referred to as ingress label edge router, or ingress LER. The ingress LSR classifies a packet or a flow to a specific LSP and pushes the applicable label on the packet. This classification of client data to an LSP occurs only once, at the ingress router, using some policy. Routers along the label switched path perform forwarding based on the top level inbound label. The label switched path terminates at the boundary between an MPLS enabled network and traditional network. The egress label switch router, the egress LER, is responsible for removing the label from the packet and forwarding the packet based on the packet's original contents, using traditional means.

1.10 BENEFIT/APPLICATION OF MPLS

1.10.1 Simple Forwarding

As MPLS uses fixed length label-based forwarding, the forwarding of each packet is entirely determined by a single indexed lookup in a switching table, using the packet's MPLS label. This simplifies the label switching router forwarding function compared to the longest prefix match algorithm required for normal datagram forwarding.

1.10.2 Traffic Engineering

One of the main advantages of MPLS is the ability to do Traffic Engineering (TE) in connectionless IP networks. TE is necessary to ensure that traffic is routed through a given network in the most efficient and reliable manner. Traffic engineering enables ISPs to route network traffic in such a way that they can offer the best service to their users in terms of throughput and delay. MPLS traffic engineering allows traffic to be distributed across the entire network infrastructure.

MPLS traffic engineering provides a way to achieve the same traffic engineering benefits of the overlay model without the need to run a separate network. With MPLS, traffic engineering attempts to control traffic on the network using Constrained Shortest Path First (CSPF) instead of using the Shortest Path First (SPF) only. CSPF creates a path that takes restrictions into account. This path may not always be the shortest path, but, for instance, it will utilize paths that are less congested.

The LSP tunnel is useful for the TE function. LSP tunnels allow operators to characterize traffic flows end-to-end within the MPLS domain by monitoring the traffic on the LSP tunnel. Traffic losses can be estimated by monitoring ingress LSR and egress LSR traffic statistics. Traffic delay can be estimated using by sending probe packets through and measuring the transit time.

One approach to engineering the network is to define a mesh of tunnels from every ingress device to every egress device. IGP, operating at an ingress device, determines which traffic should go to which egress device, and steers that traffic into the tunnel from ingress to egress. The MPLS traffic engineering path calculation and signaling modules determine the path taken by the LSP tunnel, subject to resource availability and the dynamic state of the network.

Sometimes a flow is so large that it cannot fit over a single link, so it cannot be carried by a single tunnel. In this case multiple LSP tunnels between a given ingress and egress can be configured, and the flow load shared among them. This prevents a situation where some parts of a service provider network are over-utilized, while other parts remain under-utilized. The capability to forward packets over arbitrary non-shortest paths and emulate high-speed tunnels within an MPLS domain yield a TE advantage to MPLS technology.

1.10.3 Source based QoS Routing

Source based QoS routing is a routing mechanism under which LSRs are determined in the source node (ingress LSR) based on some knowledge of resource availability in the network as well as the QoS requirements of the flows. In other words, it is a routing protocol that has expanded its path selection criteria to include QoS parameters such as available bandwidth, link and end-to-end path utilization, node resource consumption, delay and latency, including jitter.

MPLS allows decoupling of the information used for forwarding (i.e., label) from the information carried in the IP header. Also the mapping between FEC and an LSP is completely confined to the LER at the head of the LSP: the decision as to which IP packet will take a particular explicit route is totally the responsibility of the LER (ingress LSR) which computes the route. This allows MPLS to support the source based QoS routing function.

1.10.4 Virtual Private Networks

An Internet-based virtual private network (VPN) uses the open, distributed infrastructure of the Internet to transmit data between sites, maintaining privacy through the use of an encapsulation protocol to establish tunnels. A virtual private network can be contrasted with a system of owned or leased lines that can only be used by one company. The main purpose of a VPN is to give the company the same capabilities as private leased lines at much lower cost by using the shared public infrastructure. The MPLS architecture fulfils all the necessary requirements to support VPNs by establishing LSP tunnels using explicit routing. Therefore, MPLS using LSP tunnels allows service providers to deliver this popular service in an integrated manner on the same infrastructure they used to provide Internet services. Moreover, label stacking allows configuring several nested VPNs in the network infrastructure.

1.10.5 Hierarchical Forwarding

The most significant change produced by MPLS in the internet architecture is not in the routing architecture, but in forwarding architecture. This modification in the forwarding architecture has a significant impact in its ability to provide hierarchical forwarding. Hierarchical forwarding allows the encapsulation of an LSP within another LSP (label stacking or multiple level packet control).

Hierarchical forwarding is not new in network technology; ATM provides two level hierarchy forwarding with the notion of virtual path(VP) and virtual circuit(VC) i.e., two levels of packet control. MPLS, however, allows LSPs to be nested arbitrarily, providing multiple level packet control for forwarding.

1.10.6 Scalability

Label switching provides a more complete separation between inter-domain and intra-domain routing, which helps to improve the scalability of routing processes. Furthermore, MPLS scalability also benefits from FEC (flow aggregation), and label stacking for merging LSPs and nesting LSPs. The assignment of a label for each individual flow is not the desired idea for scalability because it increases the usage of labels, which consequently causes the LIB to growth as fast as the number of flows in the network. As FEC allows flow aggregation, this improves MPLS scalability. In addition, multiple LSPs associated to different FECs can be merged in a single LSP, further improving this feature. Some benefits will also be gained from LSP nesting.

1.11 SUMMARY

In conventional network layer protocols, when a packet travels from one router to the next hop an independent forwarding decision is made at each hop. Each router runs a network layer routing algorithm. As a packet travels through a network, each router analyzes the packet header. The choice of next hop for a packet is based on the header analysis and the result of running the routing algorithm. In conventional IP forwarding, the particular router will typically consider two packets to be in the same flow if they have the same network address prefix, applying the "longest prefix match" for each packet destination address. As a packet traverses the network, each hop in turn re-examines the packets and assigns it to a flow.

Label switching technology enables one to replace conventional packet forwarding based on the standard destination-based hop-by-hop forwarding paradigm with a label swapping forwarding paradigm. This is based on fixed length labels, which improves the performance of layer 3 routing, simplifies packet forwarding and enables easy scaling.