Chapter7

=#\*$,'&($(1(\* >32/\* 8!,$1-,). V=:>8U

?<F@8 D4H= ;G?DF7@5D8 F;5D9DE @< 7A@8 FAH:7D9I

Define the functions and characteristics of RSVP

Define the functions and characteristics of LDP

In this chapter, we explore how the JUNOS software uses Multiproi tocol Label Switching (MPLS) to forward user data traffic across a network. Before beginning this chapter, you should be familiar with the basic concepts of MPLS. @ou should know that a labeliswitched path (LSP) allows traffic fori warding based on label values encoded in a 4ioctet shim header placed between the Layer 2 and Layer 3 headers. The routers along the path of an LSP fall into one of four categories#ingress, trani sit, penultimate, and egress. Each router performs a specific operation when user traffic is forwarded through the LSP. @ou should be familiar with the basic configuration and establishment of an LSP using the Resource Reservation Protocol (RSVP). Each interface requires support for MPLS packets, and the routing protocol daemon is informed of which operational interfaces support RSVP and MPLS. The LSP itself uses RSVP F:(3 and E6)& messages to establish the LSP. @ou can control the actual network links used by the LSP when you configure a named path, which supplies loose and strict hops. Finally, you should know that only BGP routes, by default, are allowed to use established LSPs but that specific IPv4 destinations can be associated with a particular LSP.

In this chapter, we examine the two signaling protocols used to establish LSPs#RSVP and the Label Distribution Protocol (LDP). In addition, we investigate how each protocol operates in an MPLS network, exchanges label information, and establishes labeliswitched paths.

Signaling Protocols

The JUNOS software supports two protocols for the dynamic signaling and setup of an LSP: RSVP and LDP. Each signaling option effectively establishes an LSP and forwards user data traffic using MPLS labels. However, each of the protocols accomplishes this in different ways. Let s see how each of the signaling mechanisms works.

Resource Reservation Protocol

The >5'+%(75 >5'5($9&1+, ?(+&+7+. (RSVP) was originally designed to provide endiuser hosts with the ability to reserve network resources for data traffic flows. While this concept makes theoretical sense for a single enterprise network, it was never widely implemented for the Interi net at large. In essence, the ISPs that make up the Internet didn t want individual customers altering the operation of their networks.

One of the basic concepts of RSVP is that a traffic flow consists of an identifiable session between two endpoints. Traditionally, these endpoints were the hosts in the network. The coni cept of a session ties neatly into the concept of an LSP, which transports a traffic flow between

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two individual routers in the network. This led network designers to extend the RSVP protocol specification to support trafficiengineering capabilities. This extended specification (RSVPiTE) allows an RSVP session to be established between two routers (or endpoints) in the network for the purpose of transporting a specific traffic flow.

Many of the original RSVP components are still used in an MPLS network, including the basic packet format of an RSVP message. Figure 7.1 displays the format of an RSVP message, which includes the following:

;5('1+, \R 81&'[ The version field displays the current version of RSVP represented by the mesi sage. A constant value of 0x1 is placed in this field.

I.93' \R 81&'[ The Flags field is used to signal support for protocol extensions to neighboring RSVP routers. Currently only a single flag is defined for use in an MPLS network. The flag defi initions are:

M1& S This flag bit is currently not defined and is set to a constant value of 0.

M1& T This flag bit is currently not defined and is set to a constant value of 0.

M1& U This flag bit is currently not defined and is set to a constant value of 0.

M1& V This flag bit signals support for the reduction of refresh overhead messages. This extension allows multiple RSVP messages to be bundled together into a single message fori mat. When the bit is set to a value of 1, the local router supports the extensions. When the extensions are not supported, the flag is set to a value of 0.

C5''935 =!\*5 \U +7&5&[ This field displays the type of RSVP message encoded in the packet. The possible type codes are:

1#F:(3 2#E6)& 3#F:(3P\*\* 4#E6)&P\*\* 5#F:(3C6:\* 6#E6)&C6:\* 7#E6)&R-.5 12#S'.706 13#T81 15#D\*65\*6)3 20#M600- 25#L.(64\*2(# R3:006.46 26#L.(64\*2(# E6),-.)6

?>;@ L257/'%- \T +7&5&'[ This field displays a standard IP checksum for the entire RSVP message. When the checksum is computed, the local router assumes this field contains all zeros.

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C@B69D LTR RSVP message format

32 bits

8 8 8 8 Version Flags Message Type RSVP Checksum

Send TTL ReservedRSVP Length

Objects

>5,6 ==D \U +7&5&[ This field contains the identical value used in the TimeitoiLive (TTL) field of the IP header. It is used to detect a noniRSVP capable router along the path of an LSP.

?5'5($56 \U +7&5&[ This field is not used and must be set to a constant value of 0x00.

?>;@ D5,3&2 \T +7&5&'[ This field displays the length of the entire RSVP packet, including any optional objects that are attached to the message.

A8057&' \;9(198.5[ This variableilength field contains one or more RSVP objects. Each object is represented by a fixedilength header and a variableilength data field.

The information required to set up and maintain an RSVP session is encoded in multiple +8057&' used in the various message types. Table 7.1 displays some RSVP objects and the messages that use them. The common reference for each object is a combination of its RSVP class name in addition to its specific object title. For example, IPv4/UDP is an object within the Session class. When you reference this object as a singular entity, it is called the IPv4/UDP Session object.

7HG>D LTR RSVP Objects

Class Name Class ` Object Name C]Type ` Message Usage

Session 1 IPv4/UDP 1 F:(3

E6)&

F:(3P\*\*

E6)&P\*\*

F:(3C6:\*

E6)&C6:\*

IPv6/UDP 2 F:(3

E6)&

F:(3P\*\*

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7HG>D LTR RSVP Objects (continued)

Class Name Class ` Object Name C]Type ` Message Usage

E6)&P\*\*

F:(3C6:\*

E6)&C6:\*

LSPaTunnelaIPv4 7 F:(3

E6)&

F:(3P\*\*

E6)&P\*\*

F:(3C6:\*

E6)&C6:\*

LSPaTunnelaIPv6 8 F:(3

E6)&

F:(3P\*\*

E6)&P\*\*

F:(3C6:\*

E6)&C6:\*

RSVPaHop 3 IPv4 1 F:(3

E6)&

IPv6 2 F:(3

E6)&

Integrity 4 Integrity 1 All types

TimeaValues 5 TimeaValues 1 F:(3

E6)&

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7HG>D LTR RSVP Objects (continued)

Class Name Class ` Object Name C]Type ` Message Usage

ErroraSpec 6 IPv4 1 F:(3P\*\*

E6)&P\*\*

IPv6 2 F:(3P\*\*

E6)&P\*\*

Scope 7 IPv4 1 E6)&

IPv6 2 E6)&

Style 8 Style 1 E6)&

Flowspec 9 Reserved 1 E6)&

Integrated Services 2 E6)&

FilteraSpec 10 IPv4 1 E6)&

IPv6 2 E6)&

LSPaTunnelaIPv4 7 E6)&

LSPaTunnelaIPv6 8 E6)&

Sendera Template

11 IPv4 1 F:(3

IPv6 2 F:(3

IPv6 FlowaLabel 3 F:(3

LSPaTunnelaIPv4 7 F:(3

LSPaTunnelaIPv6 8 F:(3

Sendera Tspec

12 Integrated Services 2 F:(3

Adspec 13 Integrated Services 2 F:(3

PolicyaData 14 Type 1 PolicyaData 1 F:(3

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7HG>D LTR RSVP Objects (continued)

Class Name Class ` Object Name C]Type ` Message Usage

E6)&

Resva Confirm

15 IPv4 1 E6)&

IPv6 2 E6)&

Label 16 Label 1 E6)&

Generalized Label 2 E6)&

Waveband Switching 3 E6)&

Label Request

19 Label Request (no label

range)

1 F:(3

1 F:(3

Label Request (ATM label range)

2 F:(3

Label Request (Frame Relay label range)

3 F:(3

Generalized Label Request 4 F:(3

Juniper Networks Extension 11 F:(3

Explicit Route

20 Explicit Route 1 F:(3

Record Route

21 Record Route 1 F:(3

E6)&

Hello 22 Hello Request 1 M600-

Hello Acknowledgement 2 M600-

MessageaID 23 MessageaID 1 F:(3

E6)&

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7HG>D LTR RSVP Objects (continued)

Class Name Class ` Object Name C]Type ` Message Usage

Messagea IDaAck

24 MessageaIDaAck 1 F:(3

E6)&

MessageaIDaNack 2 F:(3

Messagea IDaList

25 MessageaIDaList 1 F:(3

E6)&

IPv4/MessageaID SrcaList 2 F:(3

IPv6/MessageaID SrcaList 3 F:(3

IPv4/MessageaID McastaList 4 F:(3

IPv6/MessageaID McastaList 5 F:(3

Detour 63 Detour 7 F:(3

Challenge 64 Challenge 1 L.(64\*2(# R3:006.46

L.(64\*2(# E6),-.)6

RestartaCap 131 RestartaCap 1 M600-

Properties 204 ObjectaType 1 F:(3

E6)&

Fast Reroute 205 Fast Reroute 1 F:(3

Fast Reroute (existing implementations)

7 F:(3

Session Attribute

207 LSPaTunnelaRA 1 F:(3

LSPaTunnel 7 F:(3

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A detailed explanation of every RSVP object listed is outside the scope of this book. Within this chapter, wetll focus only on the objects used to establish labelaswitched paths in an MPLS network.

Before we explore the format and use of RSVP objects, let s discuss the RSVP messages used in an MPLS network.

The 52"+ Message

When an MPLSicapable router sets up an LSP, it generates a F:(3 message and forwards it downstream to the egress router. The destination address of the message is the IP address of the egress router, but each device along the path examines the contents of the F:(3 message. This hopibyihop examination occurs since the ingress router sets the IP RouteriAlert option in the message s IP header. The F:(3 message may contain some of the following RSVP objects: Session, RSVPiHop, TimeiValues, Session Attribute, Sender Template, SenderiTspec, Adspec, Explicit Route, Label Request, Properties, Record Route, Integrity, Fast Reroute, and Detour.

C@B69D LTQ Sample MPLS network

10.222.29.0/24 10.222.1.0/24 10.222.45.0/24

.1 .2 .1 .2 .1 .2

Sherry 192.168.16.1

Figure 7.2 shows a simple MPLS network consisting of four routers; Sherry, Chianti, Merlot, and Chardonnay. An MPLS LSP is established from Sherry to Chardonnay using RSVP. We use the )3-% /,0) 0), 2.4\*6)) command on the Sherry router to verify that the LSP is operational:

')6\*UD36\*\*#V &.)" +(,& ,&( -\*/'1&& L.4\*6)) JDFZ c )6))2-.) C- O\*-/ D(:(6 E( T8(2&6F:(3 F JDF.:/6 c[bfc^\fabfc c[bfc^\fc^fc B, d j D36\*\*#g(-gR3:\* C-(:0 c 72),0:#67h B, ch Q-%. d

The configuration on Sherry that created the \*&'"" , $,+&)" LSP looks like this:

')6\*UD36\*\*#V &.)" 3)\*0-/$'5%-)\* (')%)3),& +(,& 0:960g)%2(8367g,:(3 D36\*\*#g(-gR3:\* !

(- c[bfc^\fabfcY 2.(6\*5:86 :00YChianti 192.168.20.1

Merlot 192.168.40.1

Chardonnay 192.168.32.1

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When the configuration was committed, Sherry generated an RSVP F:(3 message addressed to the egress address of 192.168.36.1 and sent it downstream. After some processing at the Chii anti router, the F:(3 message is advertised further downstream to Merlot. We see the message arrive at Merlot and appear in the output of a (\*:86-,(2-.) file, which is collecting RSVP information:

T,\* b` cdZ\_^Zb` EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D6))2-.T((\*29'(6 J6. b\ F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n T,\* b` cdZ\_^Zb` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` TQ),68 J6. `\ T,\* b` cdZ\_^Zb` D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbf`\_fb D T,\* b` cdZ\_^Zb` J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd T,\* b` cdZ\_^Zb` F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc

When Merlot receives this particular F:(3 message, it examines the information in the D6))2-.] and D6.76\*] objects to determine if this unique combination was already seen in a previous F:(3 message. Because this is a new LSP, we know that the message has not been seen by Merlot. This "newness! means that Merlot creates a new RSVP softistate set of information known as a ?9&2 =&9&5 I.+7/. This softistate information includes information from the F:(3 message such as the Sesi sion, Sender Template, and SenderiTspec objects. Additionally, the interface address of the previous hop along the LSP (10.222.1.1) is stored, which allows the router to send a E6)& message to the appropriate upstream device.

Because Merlot is not the egress router, it then prepares to send the F:(3 message further downstream. Before doing so, it adds the outgoing interface address (10.222.45.1) to the Record Route object and places it in the RSVPiHop object. We can see the message sent to Chardonnay in the (\*:86-,(2-.) file as

T,\* b` cdZ\_^Zb` EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb\ )-gdecebfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbf`\_fced$d\\_\_db^` T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D6))2-.T((\*29'(6 J6. b\ F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n T,\* b` cdZ\_^Zb` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` TQ),68 J6. `\ T,\* b` cdZ\_^Zb` D\*8E-'(6 J6. cb cdfbbbf`\_fb D T,\* b` cdZ\_^Zb` J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd T,\* b` cdZ\_^Zb` F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 T,\* b` cdZ\_^Zb` E68E-'(6 J6. b\ cdfbbbf`\_fc cdfbbbfcfc cdfbbbfb[fc

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After the F:(3 message reaches the egress router of Chardonnay, the resources of the LSP are established in the network by E6)& messages.

The 4.#! Message

The Chardonnay router, our LSP egress router, generates a E6)& message and forwards it upstream to Merlot. The destination address of the E6)& message is the interface address of the Merlot router. This information is gleaned from the RSVPiHop object in the F:(3 message received by Chardonnay. An individual E6)& message may contain some of the following RSVP objects: Session, RSVPiHop, TimeiValues, Style, Flowspec, FilteriSpec, Label, Record Route, and Integrity.

The first E6)& message received on Merlot is from the Chardonnay router. We see the details of this message in the output of our (\*:86-,(2-.) file:

T,\* b` cdZ\_^Zb` EDAF \*68& E6)& cdfbbbf`\_fbgVcdfbbbf`\_fc J6.Wcbd )-gdecebfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbf`\_fbed$d\\_\_db^` T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D(#06 J6. \ OO T,\* b` cdZ\_^Zb` O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` J:960 J6. \ a T,\* b` cdZ\_^Zb` E68E-'(6 J6. cb cdfbbbf`\_fb

When Merlot receives this first E6)& message, it creates an additional set of RSVP soft state information known as a >5'$ =&9&5 I.+7/. This state information is uniquely identified by the data in the Session, RSVPiHop, and Flowspec objects. The Resv State Block stores these data fields as well as the outgoing interface for the traffic flow and the style of the particular reseri vation request. Merlot then consults the Path State Block information previously stored and locates the next upstream router. This lookup is keyed against the information stored in the Sesi sion and FilteriSpec objects.

When a matching Path State Block is found, Merlot records the label advertised from the downstream router. In our particular example, Chardonnay advertised a label value of 3, sigi naling Merlot to perform penultimate hop popping (PHP). Because Merlot is not the ingress router, a new E6)& message is formulated for advertisement upstream to Chianti. Before sendi ing the message, Merlot adds its outgoing interface address (10.222.1.2) to the Record Route object and places it in the RSVPiHop object. Additionally, a label value of 100,001 is allocated and included in the Label object of the E6)& message. We can see these message details in the (\*:86-,(2-.) file on Merlot:

T,\* b` cdZ\_^Zb` EDAF )6.7 E6)& cdfbbbfcfbgVcdfbbbfcfc J6.Wcb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfbed$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D(#06 J6. \ OO

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T,\* b` cdZ\_^Zb` O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` J:960 J6. \ cddddc T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfb cdfbbbf`\_fb

When the flow of E6)& messages reaches the Sherry router, the LSP is successful established.

The 52"+6$$ Message

An RSVP F:(3P\*\* message is sent hop by hop to the ingress router from the device noticing the error. F:(3P\*\* messages do not destroy any established soft state in the network, but are used simply to signal error information, often a processing problem with a F:(3 message, to the ingress router. These messages are sent in a hopibyihop fashion upstream and are addressed to the interface address of the previous hop. A F:(3P\*\* message may contain some of the followi ing RSVP objects: Session, ErroriSpec, SenderiTemplate, and SenderiTspec.

Using Figure 7.2 as a guide, we once again build an LSP from Sherry to Chardonnay. The LSP is provided an explicit route through the network using a named path of ! "%( ,&$#!, which is applied to the LSP as so:

')6\*UD36\*\*#V &.)" 3)\*0-/$'5%-)\* (')%)3),& +(,& 0:960g)%2(8367g,:(3 D36\*\*#g(-gR3:\*7-..:# !

(- c[bfc^\fabfcY 9:.7%27(3 c\_/Y .-g8),5Y ,\*2/:\*# )(\*28(g3-,)Y

,:(3 )(\*28(g3-,) !

cdfbbbfb[fb )(\*28(Y cdfbbbfcfb )(\*28(Y cdfbbbfcccfb )(\*28(Y

2.(6\*5:86 :00Y

The final address listed in the ! "%( ,&$#! path is 10.222.111.2, which does not correi spond to the address of the Chardonnay router. This causes the F:(3 message processing to fail at Merlot, since the next hop in the explicit route is not reachable. Merlot generates a F:(3P\*\* message address to 10.222.1.1, the interface address of Chianti, to signal the ingress router of the problem. The message details are visible in the (\*:86-,(2-.) file:

T,\* b\_ d]Zd^Zdd EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb\ )-gdecedfd T,\* b\_ d]Zd^Zdd D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bbbk F\*-(- d T,\* b\_ d]Zd^Zdd M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b\_ d]Zd^Zdd C2/6 J6. \ adddd /) T,\* b\_ d]Zd^Zdd D6))2-.T((\*29'(6 J6. b\ F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n T,\* b\_ d]Zd^Zdd D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck

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T,\* b\_ d]Zd^Zdd C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b\_ d]Zd^Zdd TQ),68 J6. `\ T,\* b\_ d]Zd^Zdd D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbfcccfb D T,\* b\_ d]Zd^Zdd J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd T,\* b\_ d]Zd^Zdd F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 T,\* b\_ d]Zd^Zdd E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc

T,\* b\_ d]Zd^Zdd EDAF -\*242.:(6 F:(3P\*\* cdfbbbfcfbgVcdfbbbfcfc T,\* b\_ d]Zd^Zdd P$,0282( E-'(6Z 9:7 )(\*28( \*-'(6 JDF D36\*\*#g(-gR3:\*lce``bbbk T,\* b\_ d]Zd^Zdd EDAF )6.7 F:(3P\*\* cdfbbbfcfbgVcdfbbbfcfc J6.W\` )-gdecedfd T,\* b\_ d]Zd^Zdd D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bbbk F\*-(- d T,\* b\_ d]Zd^Zdd P\*\*-\* J6. cb 8-76 b` &:0'6 b 50:4 d 9# cdfbbbfcfb T,\* b\_ d]Zd^Zdd D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b\_ d]Zd^Zdd C),68 J6. a^ \*:(6 c\_I9,) )2"6 c\_I9,) ,6:1 L.59,) / bd I c\_dd

From Merlot s perspective, we see the arrival of the F:(3 message from Sherry, which coni tains an explicit route shown as D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbfcccfb D. As Merlot is not capable of forwarding the F:(3 message to 10.222.111.2, it generates a F:(3P\*\* message containing the error information of P$,0282( E-'(6Z 9:7 )-'\*86 \*-'(6. This message travi els upstream to the Sherry router, where the status of the LSP is listed as nonoperational. We can gather valuable information as to why the LSP is not working from the output of the )3-% /,0) 0), 2.4\*6)) 6$(6.)2&6 command:

')6\*UD36\*\*#V &.)" +(,& ,&( -\*/'1&& 1!%1\*&-#1 L.4\*6)) JDFZ c )6))2-.)

c[bfc^\fabfc

O\*-/Z c[bfc^\fc^fch D(:(6Z Q.h T8(2&6E-'(6Z dh JDF.:/6Z D36\*\*#g(-gR3:\* T8(2&6F:(3Z l.-.6k J-:7S:0:.86Z E:.7-/ P.8-72.4 (#,6Z F:816(h D%2(832.4 (#,6Z F:816(h NFLQZ LF&` F\*2/:\*# )(\*28(g3-,) D(:(6Z Q.

S:.7%27(3Z c\_I9,) b T,\* b\_ d]Zd^Zaa cdfbbbfcfbZ P$,0282( E-'(6Z 9:7 )(\*28( \*-'(6=a (2/6)< c T,\* b\_ d]Zd\_Z\_a G\*242.:(6 R:00 R\*6:(67Z O\*2 T\*, b\_ d]Zd\_Z`] bdda C-(:0 c 72),0:#67h B, dh Q-%. c

The 4.#!6$$ Message

An RSVP E6)&P\*\* message is also used to alert routers in the network to potential problems. The message is sent hop by hop to the egress router from the device noticing the error. Like the F:(3P\*\* message, E6)&P\*\* messages do not destroy any established soft state in the network.

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The messages are addressed to the IP interface address of the next downstream hop along the path. A E6)&P\*\* message may contain some of the following RSVP objects: Session, RSVPi Hop, ErroriSpec, Style, Flowspec, and FilteriSpec.

Once the \*&'"" , $,+&)" LSP is established in Figure 7.2, the interface address of the Chii anti router is changed from 10.222.29.2 /24 to 10.222.29.100 /24. This address change causes Chianti to include 10.222.29.100 in the RSVPiHop object in its next E6)& refresh message to Sherry. We see this message in the (\*:86-,(2-.) output on Chianti:

T,\* b\_ cdZa\_Za] EDAF )6.7 E6)& cdfbbbfb[fcddgVcdfbbbfb[fc J6.Wca^ 46gdebedfd T,\* b\_ cdZa\_Za] D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``ba`k F\*-(- d T,\* b\_ cdZa\_Za] M-, J6. cb cdfbbbfb[fcdded$d\`59d88 T,\* b\_ cdZa\_Za] C2/6 J6. \ adddd /) T,\* b\_ cdZa\_Za] D(#06 J6. \ OO T,\* b\_ cdZa\_Za] O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b\_ cdZa\_Za] O20(6\*] J6. cb c[bfc^\f^cfcl,-\*(e0), LQ ck T,\* b\_ cdZa\_Za] J:960 J6. \ cdddd] T,\* b\_ cdZa\_Za] E68E-'(6 J6. b\ cdfbbbfb[fcdd cdfbbbfcfb cdfbbbf`\_fb

When Sherry receives this E6)& message, it compares its contents against the current Resv State Block and finds that the interface address has been changed. Sherry then generates a E6)&P\*\* message and forwards it downstream to the egress router. This message is received by Chianti, which then forwards it along to Merlot:

T,\* b\_ cdZa\_Za] EDAF \*68& E6)&P\*\* cdfbbbfb[fcgVcdfbbbfb[fcdd J6.Wcd` 46gdebedfd T,\* b\_ cdZa\_Za] D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``ba`k F\*-(- d T,\* b\_ cdZa\_Za] M-, J6. cb cdfbbbfb[fced$d\`59d88 T,\* b\_ cdZa\_Za] P\*\*-\* J6. cb 8-76 ` &:0'6 d 50:4 d 9# cdfbbbfb[fc T,\* b\_ cdZa\_Za] D(#06 J6. \ OO T,\* b\_ cdZa\_Za] O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b\_ cdZa\_Za] O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck

T,\* b\_ cdZa\_Za] EDAF )6.7 E6)&P\*\* cdfbbbfcfcgVcdfbbbfcfb J6.Wcd` )-gdecedfd T,\* b\_ cdZa\_Za] D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``ba`k F\*-(- d T,\* b\_ cdZa\_Za] M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b\_ cdZa\_Za] P\*\*-\* J6. cb 8-76 ` &:0'6 d 50:4 d 9# cdfbbbfb[fc T,\* b\_ cdZa\_Za] D(#06 J6. \ OO T,\* b\_ cdZa\_Za] O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b\_ cdZa\_Za] O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck

The 52"+3.2$ Message

Once an LSP is established in the network, RSVP maintains its softistate data structures as long as the LSP is operational. Once the LSP is no longer needed, the state information is removed

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from the router s memory. This removal of state information is the function of the F:(3C6:\* message. The message travels downstream to the egress router, removing the Path State Block and Resv State Block information along the way. The destination address of the F:(3C6:\* mesi sage is the IP address of the egress router, but the IP RouteriAlert option is set to allow each device along the path to examine the message contents. The F:(3C6:\* message may contain some of the following RSVP objects: Session, RSVPiHop, SenderiTemplate, and SenderiTspec.

The \*&'"" , $,+&)" LSP from Figure 7.2 is operational in the network. We verify its status on the ingress router of Sherry:

')6\*UD36\*\*#V &.)" +(,& ,&( L.4\*6)) JDFZ c )6))2-.) C- O\*-/ D(:(6 E( T8(2&6F:(3 F JDF.:/6 c[bfc^\fabfc c[bfc^\fc^fc B, d j D36\*\*#g(-gR3:\* C-(:0 c 72),0:#67h B, ch Q-%. d

P4\*6)) JDFZ d )6))2-.) C-(:0 d 72),0:#67h B, dh Q-%. d

C\*:.)2( JDFZ d )6))2-.) C-(:0 d 72),0:#67h B, dh Q-%. d

Suppose the network link between the Chianti and Merlot routers now fails. This link failure causes Merlot to generate a F:(3C6:\* message addressed to the egress address of 192.168.32.1. The message replicates the information originally found in the F:(3 message that established the LSP. This allows Merlot and Chardonnay to remove all RSVP state information associated with the \*&'"" , $,+&)" LSP. We can view the contents of the message in the output of the (\*:86-,(2-.) file on Merlot:

T,\* b\_ d[Z\_^Z\_` EDAF )6.7 F:(3C6:\* c[bfc^\fc^fcgVc[bfc^\fabfc J6.W\` )-gdecebfd T,\* b\_ d[Z\_^Z\_` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``badk F\*-(- d T,\* b\_ d[Z\_^Z\_` M-, J6. cb cdfbbbf`\_fced$d\\_\_db^` T,\* b\_ d[Z\_^Z\_` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b\_ d[Z\_^Z\_` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd

The 4.#!3.2$ Message

In a similar fashion to the F:(3C6:\* message, a E6)&C6:\* message also removes RSVP state information in the network. The E6)&C6:\* message travels upstream to the ingress router in a hopibyihop fashion. The destination address of the message is the IP interface address of the previous hop along the path. The E6)&C6:\* message may contain some of the following RSVP objects: Session, RSVPiHop, Style, and FilteriSpec.

When the network link between the Chianti and Merlot routers fails, the state information on Chianti and Sherry is no longer needed. The Chianti router generates a E6)&C6:\* message addressed

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to the interface address of Sherry#10.222.29.1. The message replicates the information originally found in the E6)& message that established the LSP. We can view the output of the (\*:86-,(2-.) file on Chianti and see the E6)&C6:\* message sent upstream:

T,\* b\_ d[Z\_`Z\_] EDAF )6.7 E6)&C6:\* cdfbbbfb[fbgVcdfbbbfb[fc J6.W\_^ 46gdebedfd T,\* b\_ d[Z\_`Z\_] D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``badk F\*-(- d T,\* b\_ d[Z\_`Z\_] M-, J6. cb cdfbbbfb[fbed$d\`59d88 T,\* b\_ d[Z\_`Z\_] D(#06 J6. \ OO T,\* b\_ d[Z\_`Z\_] O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck

RSVP Objects

Now that we have some understanding of how RSVP uses its messages to establish and withi draw its softistate information, we can focus on the details of the objects used in those messages. It should be clear at this point in the chapter that the information carried in each message is the key to understanding the operation of an RSVPibased MPLS network.

The LSP]Tunnel]IPv4 Session Object The B=?O<%,,5.OC?$K =5''1+, +8057& is perhaps the most widely seen object in an MPLS neti work. Not only is the object required in every RSVP message type, but it s also the key to uniquely identifying an LSP and its softistate information. Figure 7.3 shows the format of the Session object, which includes the following fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the LSPiTunneliIPv4 Session object, a constant value of 16 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Session object falls within the Session class, which uses a value of 1.

The values assigned to the RSVP classes are encoded using one of three bit patterns. These pati terns are used when the received class value is not recognized, or unknown. The bit patterns (where b is a 0 or 1) are:

V8888888 The receipt of an unknown class value using this bit pattern causes the local router to reject the message and return an error to the originating node.

UV888888 The receipt of an unknown class value using this bit pattern causes the local router to ignore the object. It is not forwarded to any RSVP neighbors, and no error messages are generated.

UU888888 The receipt of an unknown class value using this bit pattern causes the local router to also ignore the object. In this case, however, the router forwards the object to its neighbors without examining or modifying it in any way.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The LSPiTunneliIPv4 Session object uses a value of 7 for its CiType.

F@$R =%,,5. J,6\*+1,& N66(5'' \R +7&5&'[ This field displays the IPv4 address of the LSP egress router.

?5'5($56 \T +7&5&'[ This field is not used and must be set to a constant value of 0x0000.

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C@B69D LTP The LSPaTunnelaIPv4 Session object

32 bits

8 8 8 8

Object Length

Class Number CCType Value IPv4 Tunnel Endpoint Address Reserved

Tunnel ID Extended Tunnel ID

=%,,5. FK \T +7&5&'[ This field contains a unique value generated by the ingress router of the LSP. This helps to distinguish the particular LSP from other paths originating at the same ingress router. The selected value remains constant throughout the life of the LSP.

J"&5,656 =%,,5. FK \R +7&5&'[ An ingress router places its IPv4 address in this field to furi ther identify the session. This allows the LSP to be uniquely identified by the ingressiegress router addresses. Although the use of this field is not required, the JUNOS software places the ingress address here by default.

We see the Session object appear in a F:(3 message received by the Merlot router in Figure 7.2:

T,\* b` cdZ\_^Zb` EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D6))2-.T((\*29'(6 J6. b\ F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n T,\* b` cdZ\_^Zb` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` TQ),68 J6. `\ T,\* b` cdZ\_^Zb` D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbf`\_fb D T,\* b` cdZ\_^Zb` J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd T,\* b` cdZ\_^Zb` F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc

The CiType value of 7 and the Session class of the object appears in the output as D6))2-.]. Within the object itself, we see the egress router address of 192.168.32.1 displayed along with the tunnel ID value of 44214.

The IPv4 RSVP]Hop Object The C?$K >=:?OD+\* +8057& is used to identify the IP interface address of the neighboring RSVP router. It allows each device in the network to store information in both the Path and Resv State Blocks. In addition, it is instrumental in properly routing RSVP messages in the network. Figure 7.4 shows the format of the RSVPiHop object, which contains the following fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the IPv4 RSVPiHop object, a constant value of 12 is placed in this field.

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C@B69D LTO The IPv4 RSVPaHop object

32 bits

8 8 8 8

Object LengthClass Number CCType Value

IPv4 Next/Previous Hop Address Logical Interface Handle

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The RSVPiHop object falls within the RSVPiHop class, which uses a value of 3.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The IPv4 RSVPiHop object uses a value of 1 for its CiType.

F@$R B5"&W@(5$1+%' G+\* N66(5'' \R +7&5&'[ This field displays the IPv4 address of the neighi boring RSVP router.

D+3179. F,&5(4975 G9,6.5 \R +7&5&'[ Each interface that transmits and receives RSVP messages is assigned a unique 32ibit value known as the .+3179. 1,&5(4975 29,6.5. The sending router popi ulates this field, which contains the unique ID value. This value allows the router receiving the message to associate it with the appropriate logical interface.

The RSVPiHop object also appears in F:(3 messages received by the Merlot router for the \*&'"" , $,+&)" LSP:

T,\* b` cdZ\_^Zb` EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D6))2-.T((\*29'(6 J6. b\ F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n T,\* b` cdZ\_^Zb` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` TQ),68 J6. `\ T,\* b` cdZ\_^Zb` D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbf`\_fb D T,\* b` cdZ\_^Zb` J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd T,\* b` cdZ\_^Zb` F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc

When Merlot receives the F:(3 message, it associates the 10.222.1.1 address as the interface address of the next upstream router. The logical interface handle of 0x084ec198 is stored in the Path State Block for this session. As E6)& messages arrive from the downstream router, Merlot uses the information in the RSVPiHop object to forward its own E6)& message upstream, with the address retrieved from the object encoded as the destination address. Additionally, Merlot places the logical interface handle it received in the F:(3 message into the RSVPiHop object it

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places in its own E6)& message. The inclusion of the logical handle allows the upstream router to correlate the received E6)& message with the correct interface.

The Time]Values Object The <1-5O:9.%5' +8057& is included in all F:(3 and E6)& messages used in the MPLS network. It contains a refresh value that is used by the receiving router to calculate the lifetime of the RSVP softistate information. The value advertised in the TimeiValues object is used by the local router to regenerate the appropriate message and send it to its RSVP neighbor. Figure 7.5 disi plays the format of the TimeiValues object, which includes these fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the Timei Values object, a constant value of 8 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The TimeiValues object falls within the TimeiValues class, which uses a value of 5.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The TimeiValues object uses a value of 1 for its CiType.

?54(5'2 @5(1+6 \R +7&5&'[ This field displays the refresh time, in milliseconds, of the particular RSVP message. The JUNOS software uses a default value of 30,000 (30 seconds) for the refresh period.

The Merlot router in Figure 7.2 is receiving E6)& messages for the \*&'"" , $,+&)" LSP from its downstream neighbor. The output of a (\*:86-,(2-.) file shows the details of that E6)& message:

T,\* b` cdZ\_^Zb` EDAF \*68& E6)& cdfbbbf`\_fbgVcdfbbbf`\_fc J6.Wcbd )-gdecebfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbf`\_fbed$d\\_\_db^` T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D(#06 J6. \ OO T,\* b` cdZ\_^Zb` O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` J:960 J6. \ a T,\* b` cdZ\_^Zb` E68E-'(6 J6. cb cdfbbbf`\_fb

The 30000 ms refresh time advertised in the E6)& message informs Merlot that it should expect a refresh of this RSVP state every 30 seconds. In addition, the advertised value also allows Merlot to calculate the timeout value for the state information.

C@B69D LTN The TimeaValues object

32 bits

8 8 8 8

Object Length

Class Number CCType Value Refresh Period

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The IPv4 Error]Spec Object The C?$K F((+(O=\*57 +8057& appears in either a F:(3P\*\* or E6)&P\*\* message to provide a root cause for the error message. The object includes the IP address of the router that first discovered the error, which allows all devices in the network to locate the failure point. The fields of the IPv4 ErroriSpec object, shown in Figure 7.6, include:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the IPv4 ErroriSpec object, a constant value of 12 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The ErroriSpec object falls within the ErroriSpec class, which uses a value of 6.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The IPv4 ErroriSpec object uses a value of 1 for its CiType.

F@$R J((+( B+65 N66(5'' \R +7&5&'[ This field displays the IPv4 address of the RSVP router that detected an error condition.

I.93' \U +7&5&[ This field contains flags that allow certain information to be carried in the ErroriSpec object. Currently, two flags are defined for use within RSVP. Bit 0 (0x01) is used only when the object is contained in a E6)&P\*\* message. It signifies that an active reservation was in place and remains in place on the router detecting the device. Bit 1 (0x02) is also used only when the object is contained in a E6)&P\*\* message. It signifies that a reservation failure occurred that required more resources than the recipient of the message requested.

J((+( L+65 \U +7&5&[ This field displays the major error encountered by the RSVP router.

J((+( ;9.%5 \T +7&5&'[ This field displays additional specific information pertaining to the reported error code.

For a complete list of error codes and values, please refer to Request for Comments (RFC) 2205, "Resource Reservation Protocol#Version 1 Functional Specification.!

C@B69D LTM The IPv4 ErroraSpec object

32 bits

8 8 8 8

Object Length

Class Number CCType Value IPv4 Error Node Address Flags Error Code

Error Value

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After the \*&'"" , $,+&)" LSP is established in Figure 7.2, the IP interface address of the Chianti router is changed. This causes Sherry (10.222.29.1) to generate a E6)&P\*\* message coni taining the IPv4 ErroriSpec object. The contents of this message are seen on the Merlot router:

T,\* b\_ cdZa\_Zc[ EDAF \*68& E6)&P\*\* cdfbbbfcfcgVcdfbbbfcfb J6.Wcd` )-gdecedfd T,\* b\_ cdZa\_Zc[ D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``ba`k F\*-(- d T,\* b\_ cdZa\_Zc[ M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b\_ cdZa\_Zc[ P\*\*-\* J6. cb 8-76 ` &:0'6 d 50:4 d 9# cdfbbbfb[fc T,\* b\_ cdZa\_Zc[ D(#06 J6. \ OO T,\* b\_ cdZa\_Zc[ O0-% J6. a^ \*:(6 cddI9,) )2"6 cddI9,) ,6:1 L.59,) / bd I c\_dd T,\* b\_ cdZa\_Zc[ O20(6\*] J6. cb c[bfc^\f^cfcl,-\*(e0), LQ ck

The Style Object The =&!.5 +8057& is used in a E6)& message to determine how reservations are made in the network. By default, the JUNOS software creates a unique reservation for each RSVP session and sender. This means that every new combination of Session and SenderiTemplate objects requires a new reservation of resources. This reservation style is known as 41"56 41.&5( (FF). A second reservation style called '29(56 5"\*.171& (SE) allows a single set of reserved resources for a session to be shared among multiple senders. In other words, multiple SenderiTemplate objects that share a common Session object are allowed to use the same resources. Finally, RSVP devices may use a reservation style known as #1.679(6 41.&5( (WF). This allows for a set of resources to be shared among all posi sible senders. The wildcard filter reservation style is not supported by the JUNOS software. Figure 7.7 shows the format of the Style object, which includes the following fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the Style object, a constant value of 8 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Style object falls within the Style class, which uses a value of 8.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Style object uses a value of 1 for its CiType.

I.93' \U +7&5&[ This field contains bit flags used to relay information to RSVP routers. No flags are currently defined.

A\*&1+, ;57&+( \S +7&5&'[ This field displays the type of reservation being established by the object. The field is divided into three distinct portions. The first portion of the field uses the 19 most significant bits and is a reserved value with all of the bits set to 0.

The second portion of the field uses the next two most significant bits (3 and 4) to specify whether the reservation is shared. A value of 01 is a distinct reservation and is used by the FF style. A value of 10 represents a shared reservation and is used by the WF and SE styles.

The final 3 bits of the field (0, 1, and 2) determines which senders may use the reservation. A value of 001 is a wildcard notation that allows any possible sender to utilize the resources. This

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is used by the WF reservation style. A value of 010 denotes an explicit use of resources by only known senders. This explicit notation is used by the FF and SE reservation styles.

The final two portions of the field (5 total bits) are combined to yield the three distinct reseri vation styles as follows:

01010#Fixed filter (FF) 10001#Wildcard filter (WF) 10010#Shared explicit (SE)

C@B69D LTL The Style object

32 bits

8 8 8 8

Object Length Class Number CCType Value Flags Option Vector Refer back to Figure 7.2 and the LSP established between Sherry and Chardonnay. When the Merlot router transmits a E6)& message upstream for that session, it details the specific style for the reservation in the Style object:

T,\* b` cdZ\_^Zb` EDAF )6.7 E6)& cdfbbbfcfbgVcdfbbbfcfc J6.Wcb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfbed$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D(#06 J6. \ OO T,\* b` cdZ\_^Zb` O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` J:960 J6. \ cddddc T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfb cdfbbbf`\_fb

Using the output from the (\*:86-,(2-.) file on Merlot, we see that the \*&'"" , $,+&)" LSP is using the default JUNOS software reservation style of fixed filter.

The Integrated Services Flowspec Object The C,&53(9&56 =5($175' E.+#'\*57 +8057& appears in E6)& messages and contains information peri taining to the bandwidth request of the LSP, if any. The format and use of the object fields was designed for a controlled load environment where average and peak data rates could be defined. Modern implementations, including the JUNOS software, don t use these fields as they were origii nally intended. Instead, the bandwidth reservation for the LSP is placed there. Figure 7.8 details the format of the Integrated Services (IntServ) Flowspec object, which includes the following fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the Intserv Flowspec object, a constant value of 36 is placed in this field.

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L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Intserv Flowspec object falls within the Flowspec class, which uses a value of 9.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Intserv Flowspec object uses a value of 2 for its CiType.

;5('1+, B%-85( \T +7&5&'[ This 2ioctet field uses the first 4 bits to encode the version of the object message format. A constant value of 0 is placed in this portion of the field. The remaining 20 bits of the field are reserved and must be set to a constant value of 0x00000.

I.+#'\*57 D5,3&2 \T +7&5&'[ This field displays the total number of 32ibit words that make up the Service portion of the object. When used in an MPLS environment, this includes all of the remaining fields in the figure. A constant value of 7 is placed in this field.

>5($175 B%-85( \U +7&5&[ This field displays the type of Integrated Service this Flowspec object supports. A constant value of 5 is placed in this field to represent a controlled load session.

?5'5($56 \U +7&5&[ This field is not used and is set to a constant value of 0x00.

K9&9 D5,3&2 \T +7&5&'[ This field displays the total number of 32ibit words that make up the data portion of the object. As with the Flowspec length field, this includes all of the remaining fields in the figure. A constant value of 6 is placed in this field.

@9(9-5&5( FK \U +7&5&[ This field displays the ID value associated with the controlled load data. For the IntServ Flowspec object, a value of 127 is placed in this field.

@9(9-5&5( I.93' \U +7&5&[ This field contains bit flags used to advertise information to other routers concerning the object. No flag values are currently defined, and this field is set to a coni stant value of 0x00.

@9(9-5&5( D5,3&2 \T +7&5&'[ This field displays the total number of 32ibit words that make up the parameter portion of the object. As before, this includes all of the remaining fields in the figure. A constant value of 5 is placed in this field.

=+/5, M%7/5& ?9&5 \R +7&5&'[ This field displays the bandwidth reservation request for the LSP, if one was configured. A value of 0x00000000 in this field represents a reservation with no bandwidth requirement.

=+/5, M%7/5& >1 5 \R +7&5&'[ This field also displays the bandwidth reservation request for the LSP. Again, a value of 0x00000000 means that no bandwidth was requested.

@59/ K9&9 ?9&5 \R +7&5&'[ This field was originally designed to display the maximum load of data able to be sent through the reservation. This field is not used by the JUNOS software, and a constant value of 0x7f800000 is placed in this field, which represents an infinite peak bandi width limit.

C1,1-%- @+.1756 <,1& \R +7&5&'[ This field displays the smallest packet size supported through the LSP. The router treats all packets smaller than 20 bytes as if they were 20 bytes in length.

C9"1-%- @97/5& >1 5 \R +7&5&'[ This field displays the largest packet size supported through the LSP. The router treats all packets larger than 1500 bytes as if they were 1500 bytes in length.

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C@B69D LTK The Integrated Services Flowspec object

32 bits

8 8 8 8

Object Length Class Number CCType Value Version Number Flowspec Length Service Number Reserved

Data Length Parameter ID

Parameter Flags

Parameter Length Token Bucket Rate Token Bucket Size Peak Data Rate Minimum Policed Unit Maximum Packet Size

Using the \*&'"" , $,+&)" LSP in Figure 7.2 as a guide, the IntServ Flowspec object is cari ried in the E6)& messages that sets up and maintains the LSP. The Merlot router is sending a E6)& message upstream to Chianti, whose contents are visible in a (\*:86-,(2-.) file:

T,\* b` cdZ\_^Zb` EDAF )6.7 E6)& cdfbbbfcfbgVcdfbbbfcfc J6.Wcb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfbed$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D(#06 J6. \ OO T,\* b` cdZ\_^Zb` O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` J:960 J6. \ cddddc T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfb cdfbbbf`\_fb

Within the object, we see that no bandwidth requests are configured for this LSP. This is evii dent by the \*:(6 d9,) and )2"6 d9,) output on the router. The infinite peak data rate assoi ciated with the LSP is represented as ,6:1 L.59,), while the minimum (/) and maximum (I) packet sizes are also displayed.

The LSP]Tunnel]IPv4 Filter]Spec Object The B=?O<%,,5.OC?$K E1.&5(O=\*57 +8057& is contained in a E6)& message and is used to uniquely identify the sender for the LSP. This information is useful for sharing resources in the network for a single RSVP session with multiple senders. The shared explicit reservation style requires this information in the Resv State Block to adequately allocate the network resources. Figure 7.9 shows the format of the FilteriSpec object, which includes the following fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the LSPiTunneliIPv4 FilteriSpec object, a constant value of 12 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The FilteriSpec object falls within the FilteriSpec class, which uses a value of 10.

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C@B69D LTJ The LSPaTunnelaIPv4 FilteraSpec object

32 bits

8 8 8 8

Object Length Class Number CCType Value

IPv4 Tunnel Sender Address ReservedLSP ID LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The LSPiTunneliIPv4 FilteriSpec object uses a value of 7 for its CiType.

F@$R =%,,5. >5,65( N66(5'' \R +7&5&'[ This field displays the IPv4 address of the LSP ingress router.

?5'5($56 \T +7&5&'[ This field is not used and must be set to a constant value of 0x0000.

D>@ FK \T +7&5&'[ This field contains a unique value generated by the ingress router of the LSP. This helps to distinguish the particular sender and its resources from other paths originating at the same ingress router for the same RSVP session.

We can see the FilteriSpec object in a E6)& message received by the Merlot router in Figure 7.2:

T,\* b` cdZ\_^Zb` EDAF \*68& E6)& cdfbbbf`\_fbgVcdfbbbf`\_fc J6.Wcbd )-gdecebfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbf`\_fbed$d\\_\_db^` T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D(#06 J6. \ OO T,\* b` cdZ\_^Zb` O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` J:960 J6. \ a T,\* b` cdZ\_^Zb` E68E-'(6 J6. cb cdfbbbf`\_fb

The CiType value of 7 and the FilteriSpec class of the object appear in the output as O20(6\*]. Within the object itself, we see the ingress router address of 192.168.16.1 displayed along with the LSP ID value of 1.

The LSP]Tunnel]IPv4 Sender Template Object The B=?O<%,,5.OC?$K =5,65( <5-\*.9&5 +8057& is contained in a F:(3 message and is used to uniquely identify the sender for the LSP. This information contained in this object is identical to that found in the LSPiTunneliIPv4 FilteriSpec object. As such, it is useful for differentiating among sending sources, or LSP IDs, within a single RSVP session. This information is stored in the Path State Block for each router along the path of the LSP. Figure 7.10 displays the format of the Sender Template object, which includes these fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the LSPi TunneliIPv4 Sender Template object, a constant value of 12 is placed in this field.

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C@B69D LTRS The LSPaTunnelaIPv4 Sender Template object

32 bits

8 8 8 8

Object Length Class Number CCType Value

IPv4 Tunnel Sender Address ReservedLSP ID L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Sender Template object falls within the Sender Template class, which uses a value of 11.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The LSPiTunneliIPv4 Sender Template object uses a value of 7 for its CiType.

F@$R =%,,5. >5,65( N66(5'' \R +7&5&'[ This field displays the IPv4 address of the LSP ingress router.

?5'5($56 \T +7&5&'[ This field is not used and must be set to a constant value of 0x0000.

D>@ FK \T +7&5&'[ This field contains a unique value generated by the ingress router of the LSP. This helps to distinguish the particular sender and its resources from other paths originating at the same ingress router for the same RSVP session.

Using Figure 7.2 as a guide, we can view a F:(3 message arriving on the Merlot router for the \*&'"" , $,+&)" LSP:

T,\* b` cdZ\_^Zb` EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D6))2-.T((\*29'(6 J6. b\ F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n T,\* b` cdZ\_^Zb` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` TQ),68 J6. `\ T,\* b` cdZ\_^Zb` D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbf`\_fb D T,\* b` cdZ\_^Zb` J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd T,\* b` cdZ\_^Zb` F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc

The CiType value of 7 and the Sender Template class of the object appear in the output as D6.76\*]. Within the object itself, we see the ingress router address of 192.168.16.1 displayed along with the LSP ID value of 1.

The Integrated Services Sender]Tspec Object The C,&53(9&56 =5($175' =5,65(O<'\*57 +8057& appears in F:(3 messages and contains informai tion pertaining to the bandwidth request of the LSP, if any. Like the IntServ Flowspec object,

Signaling Protocols OKR

the format and use of the object fields was designed for a controlled load environment where average and peak data rates could be defined. Modern implementations, including the JUNOS software, place the bandwidth reservation for the LSP in these fields. Figure 7.11 details the fori mat of the Integrated Services (IntServ) SenderiTspec object, which includes the following:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the Intserv SenderiTspec object, a constant value of 36 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Intserv SenderiTspec object falls within the SendteriTspec class, which uses a value of 12.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Intserv SenderiTspec object uses a value of 2 for its CiType.

;5('1+, B%-85( \T +7&5&'[ This 2ioctet field uses the first 4 bits to encode the version of the object message format. A constant value of 0 is placed in this portion of the field. The remaining 20 bits of the field are reserved and must be set to a constant value of 0x00000.

='\*57 D5,3&2 \T +7&5&'[ This field displays the total number of 32ibit words that make up the Service portion of the object. When used in an MPLS environment, this includes all of the remaining fields in the figure. A constant value of 7 is placed in this field.

>5($175 B%-85( \U +7&5&[ This field displays the type of Integrated Service this SenderiTspec Object supports. A constant value of 1 is placed in this field to represent a default controlled load session.

?5'5($56 \U +7&5&[ This field is not used and is set to a constant value of 0x00.

K9&9 D5,3&2 \T +7&5&'[ This field displays the total number of 32ibit words that make up the data portion of the object. As with the Tspec Length field, this includes all of the remaining fields in the figure. A constant value of 6 is placed in this field.

@9(9-5&5( FK \U +7&5&[ This field displays the ID value associated with the controlled load data. For the IntServ SenderiTspec object, a value of 127 is placed in this field.

@9(9-5&5( I.93' \U +7&5&[ This field contains bit flags used to advertise information to other routers concerning the object. No flag values are currently defined, and this field is set to a coni stant value of 0x00.

@9(9-5&5( D5,3&2 \T +7&5&'[ This field displays the total number of 32ibit words that make up the parameter portion of the object. As before, this includes all of the remaining fields in the figi ure. A constant value of 5 is placed in this field.

=+/5, M%7/5& ?9&5 \R +7&5&'[ This field displays the bandwidth reservation request for the LSP, if one was configured. A value of 0x00000000 in this field represents a reservation with no bandwidth requirement.

=+/5, M%7/5& >1 5 \R +7&5&'[ This field also displays the bandwidth reservation request for the LSP. Again, a value of 0x00000000 means that no bandwidth was requested.

@59/ K9&9 ?9&5 \R +7&5&'[ This field was originally designed to display the maximum load of data able to be sent through the reservation. This field is not used by the JUNOS software, and a constant value of 0x7f800000 is placed in this field, which represents an infinite peak bandwidth limit.

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C@B69D LTRR The Integrated Services SenderaTspec object

C1,1-%- @+.1756 <,1& \R +7&5&'[ This field displays the smallest packet size supported through the LSP. The router treats all packets smaller than 20 bytes as if they were 20 bytes in length.

C9"1-%- @97/5& >1 5 \R +7&5&'[ This field displays the largest packet size supported through the LSP. The router treats all packets larger than 1500 bytes as if they were 1500 bytes in length.

F:(3 messages for the \*&'"" , $,+&)" LSP in Figure 7.2 are received by the Merlot router. We can view the contents of these messages in the output of a (\*:86-,(2-.) file:

T,\* b` cdZ\_^Zb` EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D6))2-.T((\*29'(6 J6. b\ F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n T,\* b` cdZ\_^Zb` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` TQ),68 J6. `\ T,\* b` cdZ\_^Zb` D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbf`\_fb D T,\* b` cdZ\_^Zb` J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd T,\* b` cdZ\_^Zb` F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc

Within the object, we see that no bandwidth requests are configured for this LSP. This is evii dent by the \*:(6 d9,) and )2"6 d9,) output on the router. The infinite peak data rate assoi ciated with the LSP is represented as ,6:1 L.59,), while the minimum (/) and maximum (I) packet sizes are also displayed.

32 bits

8 8 8 8

Object Length Class Number CCType Value Version Number Tspec Length Service Number Reserved Data Length Parameter ID

Parameter Flags

Parameter Length Token Bucket Rate Token Bucket Size Peak Data Rate Minimum Policed Unit Maximum Packet Size

Signaling Protocols OKP

The Label Object The B985. +8057& is contained in E6)& messages and advertises an MPLS label value upstream to the neighboring router. The label is used by that upstream router to forward packets within the LSP to the advertising router. The allocation of a label value for inclusion in this object must be prompted by a request for label in the F:(3 message for this LSP. Figure 7.12 displays for fields for the Label object:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the Label object, a constant value of 8 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Label object falls within the Label class, which uses a value of 16.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Label object uses a value of 1 for its CiType.

D985. ;9.%5 \R +7&5&'[ This field contains the label value advertised by the downstream router. The value is rightijustified within the 32ibit field and occupies bits 0 through 19.

C@B69D LTRQ The Label object

32 bits

8 8 8 8

Object Length

Class Number CCType Value Label Value

We can see the Label object in a E6)& message received by the Merlot router in Figure 7.2:

T,\* b` cdZ\_^Zb` EDAF \*68& E6)& cdfbbbf`\_fbgVcdfbbbf`\_fc J6.Wcbd )-gdecebfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbf`\_fbed$d\\_\_db^` T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D(#06 J6. \ OO T,\* b` cdZ\_^Zb` O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` J:960 J6. \ a T,\* b` cdZ\_^Zb` E68E-'(6 J6. cb cdfbbbf`\_fb

The egress router of Chardonnay (10.222.45.2) advertises a label value of 3 to Merlot, which requests that PHP be performed for this LSP. Merlot stores this information in its RSVP soft state, allocates its own label value, and advertises a new E6)& message upstream to Chianti:

T,\* b` cdZ\_^Zb` EDAF )6.7 E6)& cdfbbbfcfbgVcdfbbbfcfc J6.Wcb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfbed$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /)

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T,\* b` cdZ\_^Zb` D(#06 J6. \ OO T,\* b` cdZ\_^Zb` O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` J:960 J6. \ cddddc T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfb cdfbbbf`\_fb

The Label Request Object The B985. >5)%5'& +8057& is contained in F:(3 messages and prompts the advertisement of label values upstream in E6)& messages. @ou can use three different forms of Label Request objects in an MPLS network. The first request type doesn t specify a specific range of labels, which allows the downstream routers to allocate any possible value. This request type is the only form used by the JUNOS software. The other two label request types allow for an allocation from either an ATM or Frame Relay label range. Figure 7.13 shows the format of the Label Request object, which includes the following fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. For the Label Request object, a constant value of 8 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Label Request object falls within the Label Request class, which uses a value of 19.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Label Request object uses a value of 1 for its CiType.

?5'5($56 \T +7&5&'[ This field is not used and is set to a constant value of 0x0000.

D9!5( S @(+&+7+. FK \T +7&5&'[ This field contains information about the Layer 3 protocol cari ried in the LSP. The standard EtherType value of 0x0800 is used in this field to represent IPv4.

C@B69D LTRP The Label Request object

32 bits

8 8 8 8

Object Length

Class Number CCType Value Reserved

Layer 3 Protocol ID

Referring back to the LSP created in Figure 7.2, we can view the Label Request object in the F:(3 message received by Merlot:

T,\* b` cdZ\_^Zb` EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb\ )-gdecedfd T,\* b` cdZ\_^Zb` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ ``bc`k F\*-(- d T,\* b` cdZ\_^Zb` M-, J6. cb cdfbbbfcfced$d\`68c[\ T,\* b` cdZ\_^Zb` C2/6 J6. \ adddd /) T,\* b` cdZ\_^Zb` D6))2-.T((\*29'(6 J6. b\ F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n T,\* b` cdZ\_^Zb` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck T,\* b` cdZ\_^Zb` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd T,\* b` cdZ\_^Zb` TQ),68 J6. `\

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T,\* b` cdZ\_^Zb` D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbf`\_fb D T,\* b` cdZ\_^Zb` J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd T,\* b` cdZ\_^Zb` F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 T,\* b` cdZ\_^Zb` E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc

The upstream router of Chianti (10.222.1.1) has requested that a label be allocated for the \*&'"" , $,+&)" LSP being established by this message. The P(36\*C#,6 d$\dd notation informs the Merlot router that IPv4 data traffic will be using this LSP once it is operational.

The Explicit Route Object The F"\*.171& >+%&5 +8057& (ERO) is contained in F:(3 messages and allows the ingress router to specify the path of the LSP through the network by containing a list of nodes, defined as a subi object, through which the RSVP messages must pass. These nodes are in the form of an IPv4 prei fix, an IPv6 prefix, or an Autonomous System number, with the JUNOS software supporting just IPv4 prefixes. When the F:(3 message is received by a router, the ERO is examined to first deteri mine if the first node is strictly or loosely defined. The local router then determines whether the first node address in the ERO equals the local router s address. At this point, one of two possible scenarios exists. If the first node in the ERO is loosely defined and the local address is not equal to the address listed in the ERO, the local router processes the F:(3 message and forwards it to the address listed in the ERO.

The second scenario occurs when the first ERO address is strictly defined, in which case the local address must match the ERO address in order for the local router to process the F:(3 mesi sage. If the address values do not match, the local router does not process the message and instead generates a F:(3P\*\* message and forwards the error message back to the ingress router. Assumi ing that the strict hop is correctly defined, the local router creates its local Path State Block and prepares to forward the message further downstream. Before doing so, however, the first address in the ERO is removed to allow the next downstream router to perform the same sanity checks we ve discussed here.

Figure 7.14 displays the fields of the Explicit Route object when it contains IPv4 prefixes. The various fields are as follows:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Explicit Route Object falls within the Explicit Route class, which uses a value of 20.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Explicit Route object uses a value of 1 for its CiType.

D 81& 9,6 =!\*5 \U +7&5&[ The most significant bit in this 1ioctet field is called the L bit and is used to denote if the included address is loosely or strictly defined. When the bit is set to a value of 1, the address is a loose node. Strict node addresses are defined by a value of 0 for this bit.

The remaining 7 bits in the field encode the type of address contained in the subobject. For an IPv4 address, a constant value of 0x01 is used in this field.

D5,3&2 \U +7&5&[ This field displays the length of the subobject, including the type and length fields. For an IPv4 address, a constant value of 0x08 is used in this field.

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F@$R N66(5'' \R +7&5&'[ This field contains the IPv4 address listed as a node along the path.

@(541" D5,3&2 \U +7&5&[ This field displays the prefix length of the preceding IPv4 address. For a host address, the default configuration, a constant value of 32 is placed in this field.

?5'5($56 \U +7&5&[ This field is not used and is set to a constant value of 0x00.

C@B69D LTRO The Explicit Route object

32 bits

8 8 8 8

Object Length

Class Number CCType Value L Bit and Type Length

IPv4 Address IPv4 Address (continued) Prefix Length Reserved

The Sherry router in Figure 7.2 generates a F:(3 message for the \*&'"" , $,+&)" LSP, which contains the strictihop address in the ERO. We can view this information in the output of a (\*:86-,(2-.) file on Sherry:

I:# cb cbZd[Zc] EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb` 46gdebedfd I:# cb cbZd[Zc] D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db\_k F\*-(- d I:# cb cbZd[Zc] M-, J6. cb cdfbbbfb[fced$d\\_b\b^` I:# cb cbZd[Zc] C2/6 J6. \ adddd /) I:# cb cbZd[Zc] D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb cbZd[Zc] D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb cbZd[Zc] C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb cbZd[Zc] TQ),68 J6. `\ I:# cb cbZd[Zc] D\*8E-'(6 J6. b\ cdfbbbfb[fb D cdfbbbfcfb D cdfbbbf`\_fb D I:# cb cbZd[Zc] J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb cbZd[Zc] F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb cbZd[Zc] E68E-'(6 J6. cb cdfbbbfb[fc

The D\*8E-'(6 output contains the ERO information within the F:(3 message. Each of the three downstream routers is specified as a strictihop node along the path. The LSP should first traverse the router whose address is 10.222.29.2 (Chianti); it will then be sent to 10.222.1.2 (Meri lot) before reaching the final address of 10.222.45.2 (Chardonnay). Because the final address in the ERO equals the address of the egress router, 192.168.36.1, Chardonnay stops processing the F:(3 message and generates a corresponding E6)& message for transmission upstream.

The Record Route Object The >57+(6 >+%&5 +8057& (RRO) may be contained in either a F:(3 or a E6)& message. The RRO contains subobjects that describe the nodes through which the message has passed. These node addresses are in the form of an IPv4 prefix or an IPv6 prefix. In addition, a label value for

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the RSVP session may be recorded in a subobject within the RRO. Currently, the JUNOS softi ware supports only an IPv4 prefix address in the Record Route object.

The object is useful for troubleshooting the operation of an LSP, but it mainly allows routers in the network to detect loops during the setup of an LSP. When an RSVP router receives a mesi sage that contains a Record Route object, the contents of that object are examined. If the local router finds one of its local addresses in the object fields, a loop has formed and the message is not processed any further. In addition, the local router generates an error message (either a F:(3P\*\* or a E6)&P\*\*) and sends it to the router from which it received the original message. The fields used for IPv4 addresses in the Record Route object are displayed in Figure 7.15 and include the following:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Record Route object falls within the Record Route class, which uses a value of 21.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Record Route object uses a value of 1 for its CiType.

=!\*5 \U +7&5&[ This field encodes the type of address contained in the subiobject. For an IPv4 address, a constant value of 0x01 is used in this field.

D5,3&2 \U +7&5&[ This field displays the length of the subobject, including the type and length fields. For an IPv4 address, a constant value of 0x08 is used in this field.

F@$R N66(5'' \R +7&5&'[ This field contains a 32ibit host address that represents the router processing the RSVP message. While any valid networkiaccessible address is allowed here, the JUNOS software places the address of the router s outgoing interface in this field.

@(541" D5,3&2 \U +7&5&[ This field displays the prefix length of the preceding IPv4 address. A constant value of 32 is placed in this field.

I.93' \U +7&5&[ This field contains flags that alert other routers in the network about the capai bilities or conditions of the local node. Currently, four flag values are defined:

M1& V This flag bit, 0x01, is set to indicate that the next downstream link from the router is protected by a local repair mechanism, such as fast reroute link protection. The flag is set only when the Session Attribute object requests that link protection be enabled for the LSP.

M1& U This flag bit, 0x02, is set to indicate that the local router is actively using a repair mechanism to maintain the LSP due to some outage condition.

M1& T This flag bit, 0x04, is set to indicate that the local router has a backup path enabled that provides the same bandwidth reservation guarantees as established for an LSP protected through a local protection scheme.

M1& S This flag bit, 0x08, is set to indicate that the next downstream node as well as the downstream link is protected by a local repair mechanism, such as fast reroute node proteci tion. This flag is set only when the next downstream node is protected against failure and the Session Attribute object requests that node protection be enabled for the LSP.

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C@B69D LTRN The Record Route object

32 bits

8 8 8 8

Object Length

Class Number CCType Value Type Length

IPv4 Address IPv4 Address (continued) Prefix Length Flags

The Merlot router is receiving both F:(3 and E6)& messages for the \*&'"" , $,+&)" LSP in Figure 7.2. A Record Route object is present in both types of messages:

I:# cb c`Zd`Zcb EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wbb` )-gdecedfd I:# cb c`Zd`Zcb D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db\_k F\*-(- d I:# cb c`Zd`Zcb M-, J6. cb cdfbbbfcfced$d\\_b\d88 I:# cb c`Zd`Zcb C2/6 J6. \ adddd /) I:# cb c`Zd`Zcb D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c`Zd`Zcb D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c`Zd`Zcb C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c`Zd`Zcb TQ),68 J6. `\ I:# cb c`Zd`Zcb D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbf`\_fb D I:# cb c`Zd`Zcb J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c`Zd`Zcb F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c`Zd`Zcb E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc

I:# cb c`Zd`Zcb EDAF \*68& E6)& cdfbbbf`\_fbgVcdfbbbf`\_fc J6.Wcbd )-gdecebfd I:# cb c`Zd`Zcb D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db\_k F\*-(- d I:# cb c`Zd`Zcb M-, J6. cb cdfbbbf`\_fbed$d\\_]bb^` I:# cb c`Zd`Zcb C2/6 J6. \ adddd /) I:# cb c`Zd`Zcb D(#06 J6. \ OO I:# cb c`Zd`Zcb O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c`Zd`Zcb O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c`Zd`Zcb J:960 J6. \ a I:# cb c`Zd`Zcb E68E-'(6 J6. cb cdfbbbf`\_fb

Within each message type, the E68E-'(6 output contains the information encoded within the RRO. When we examine the F:(3 message, which is first in the output, we find that the 10.222.29.1 router (Sherry) processed the message first followed by the 10.222.1.1 router (Chii anti). Because none of Merlot s local interfaces appear in the RRO, the F:(3 message is proi cessed locally and Merlot adds its own downstream interface address (10.22.45.1) to the RRO before sending the message to Chardonnay.

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When Merlot receives a E6)& message for the LSP from Chardonnay, the RRO contains just the address of the egress router, 10.222.45.2. As with the F:(3 message, Merlot examines the object in the E6)& message to ensure that one of its local addresses doesn t appear. After peri forming this check, Merlot processes the message and sends a corresponding E6)& message upstream to Chianti after adding its outgoing interface address of 10.222.1.2 to the object.

The Detour Object The G5&+%( +8057& is contained in a F:(3 message, which establishes a fast reroute detour in the network. This F:(3 message inherits the Session, SenderiTemplate, and Session Attribute objects from the established LSP. This allows the detour path to be associated with the main RSVP session on all possible routers. The Detour object itself lists the originating node of the F:(3 message, the point of local repair, and the address of the downstream node being proi tected against failures. These ID values may be repeated in a single Detour object when an RSVP router merges multiple detour paths as they head toward the egress router.

We discuss the functionality of an LSP supporting fast reroute in greater detail in Chapter 8, "Advanced MPLS.!

Figure 7.16 displays the fields of the Detour object, which include the following:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Detour object falls within the Detour class, which uses a value of 63.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Detour object uses a value of 7 for its CiType.

D+79. ?5\*91( B+65 FK \R +7&5&'[ This field encodes the address of the router creating the detour path through the network. While any possible address on the local router may be used, the JUNOS software places the address of the outgoing interface in this field.

N$+16 B+65 FK \R +7&5&'[ This field encodes the router ID of the downstream node that is being protected against failures.

C@B69D LTRM The Detour object

32 bits

8 8 8 8

Object Length Class Number CCType Value

Local Repair Node ID Avoid Node ID

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C@B69D LTRL Fast reroute LSP establishment

Sangiovese

Shiraz 192.168.24.1

192.168.36.1 10.222.4.0/24 .1 .2

.2

.1 .1

.1

10.222.28.0/24 10.222.30.0/24

10.222.44.0/24 10.222.46.0/24

.1

.2

.2 .2 10.222.29.0/24 10.222.1.0/24

10.222.45.0/24

.1

.2 .1 .2

.1 .2

Sherry

Chianti

Chardonnay 192.168.16.1

192.168.20.1

192.168.32.1

Figure 7.17 shows the \*&'"" , $,+&)" LSP now configured to support fast reroute. Once the LSP becomes established through the Chianti, Merlot, and Chardonnay routers, the ingress router and all transit routers create detour paths through the network to protect against link and node failures. Sherry, the ingress router, creates a detour through the Sangiovese and Shiraz routers before reaching the egress router of Chardonnay. In the output of a (\*:86-,(2-.) file on Sherry, we first see the F:(3 message establishing the LSP followed by the generation of a seci ond F:(3 message establishing the detour path:

I:# cb c]Z`cZdc EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wb`` 46gdebedfd I:# cb c]Z`cZdc D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db]k F\*-(- d I:# cb c]Z`cZdc M-, J6. cb cdfbbbfb[fced$d\\_b\b^` I:# cb c]Z`cZdc C2/6 J6. \ adddd /) I:# cb c]Z`cZdc D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c]Z`cZdc D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c]Z`cZdc C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c]Z`cZdc TQ),68 J6. `\ I:# cb c]Z`cZdc D\*8E-'(6 J6. b\ cdfbbbfb[fb D cdfbbbfcfb D cdfbbbf`\_fb D I:# cb c]Z`cZdc J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c]Z`cZdc F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c]Z`cZdc E68E-'(6 J6. cb cdfbbbfb[fc I:# cb c]Z`cZdc O:)(E6\*-'(6 J6. bd F\*2-l]hdk M-, ^ S@ d9,) I:# cb c]Z`cZdc L.80'76 d$dddddddd P$80'76 d$dddddddd

I:# cb c]Z`cZd` EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wba^ :(gdecedfd I:# cb c]Z`cZd` D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db]k F\*-(- d

Merlot 192.168.40.1

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I:# cb c]Z`cZd` M-, J6. cb cdfbbbfb\fced$d\\_b\d88 I:# cb c]Z`cZd` C2/6 J6. \ adddd /) I:# cb c]Z`cZd` D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c]Z`cZd` D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c]Z`cZd` C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c]Z`cZd` TQ),68 J6. `\ I:# cb c]Z`cZd` D\*8E-'(6 J6. b\ cdfbbbfb\fb D cdfbbbf`fb D cdfbbbf``fb D I:# cb c]Z`cZd` J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c]Z`cZd` F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c]Z`cZd` E68E-'(6 J6. cb cdfbbbfb\fc I:# cb c]Z`cZd` Q6(-'\* J6. cb S\*:.83 5\*-/ cdfbbbfb\fc (- :&-27 c[bfc^\fbdfc

Within the detour F:(3 message type, we see the same information in the D6))2-.], D6))2-.T((\*29'(6, and D6.76\*] objects. The configured ERO (D\*8E-'(6) details the path through the network for the detour, whereas the Detour object itself lists the outgoing interface on the Sherry router (10.222.28.1) and the protected downstream node of Chianti (192.168.20.1).

Chianti, the first transit router, also creates a detour path to the egress router to protect the LSP against failures associated with the Merlot router. This detour also uses Sangiovese, Shiraz, and Chardonnay as its network path. When the Sangiovese router receives the detour F:(3 mesi sages from both Sherry and Chianti, it finds that they belong to the same RSVP session. This allows Sangiovese to merge the detour paths together and send a single F:(3 message downi stream to Shiraz. During this merge process, the Detour object lists both Sherry (10.222.28.1) and Chianti (10.222.30.2) as local repair nodes. The output of a (\*:86-,(2-.) file on Sangioi vese shows the receipt of these two F:(3 messages and the generation of the merged F:(3 mesi sage sent downstream:

I:# cb c]Z`aZ\_\_ EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wba^ :(gdecedfd I:# cb c]Z`aZ\_\_ D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db]k F\*-(- d I:# cb c]Z`aZ\_\_ M-, J6. cb cdfbbbfb\fced$d\\_b\d88 I:# cb c]Z`aZ\_\_ C2/6 J6. \ adddd /) I:# cb c]Z`aZ\_\_ D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c]Z`aZ\_\_ D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c]Z`aZ\_\_ C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c]Z`aZ\_\_ TQ),68 J6. `\ I:# cb c]Z`aZ\_\_ D\*8E-'(6 J6. b\ cdfbbbfb\fb D cdfbbbf`fb D cdfbbbf``fb D I:# cb c]Z`aZ\_\_ J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c]Z`aZ\_\_ F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c]Z`aZ\_\_ E68E-'(6 J6. cb cdfbbbfb\fc I:# cb c]Z`aZ\_\_ Q6(-'\* J6. cb S\*:.83 5\*-/ cdfbbbfb\fc (- :&-27 c[bfc^\fbdfc

I:# cb c]Z`aZ\_\_ EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wb`` )-gdebedfd I:# cb c]Z`aZ\_\_ D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db]k F\*-(- d I:# cb c]Z`aZ\_\_ M-, J6. cb cdfbbbfadfbed$d\\_b\aad

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I:# cb c]Z`aZ\_\_ C2/6 J6. \ adddd /) I:# cb c]Z`aZ\_\_ D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c]Z`aZ\_\_ D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c]Z`aZ\_\_ C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c]Z`aZ\_\_ TQ),68 J6. `\ I:# cb c]Z`aZ\_\_ D\*8E-'(6 J6. b\ cdfbbbfadfc D cdfbbbf`fb D cdfbbbf``fb D I:# cb c]Z`aZ\_\_ J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c]Z`aZ\_\_ F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c]Z`aZ\_\_ E68E-'(6 J6. bd cdfbbbfadfb cdfbbbfb[fc I:# cb c]Z`aZ\_\_ Q6(-'\* J6. cb S\*:.83 5\*-/ cdfbbbfadfb (- :&-27 c[bfc^\f`dfc

I:# cb c]Z`aZ\_\_ EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wb`` 56gdedebfd I:# cb c]Z`aZ\_\_ D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db]k F\*-(- d I:# cb c]Z`aZ\_\_ M-, J6. cb cdfbbbf`fced$d\\_^\_d88 I:# cb c]Z`aZ\_\_ C2/6 J6. \ adddd /) I:# cb c]Z`aZ\_\_ D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c]Z`aZ\_\_ D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c]Z`aZ\_\_ C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c]Z`aZ\_\_ TQ),68 J6. `\ I:# cb c]Z`aZ\_\_ D\*8E-'(6 J6. bd cdfbbbf`fb D cdfbbbf``fb D I:# cb c]Z`aZ\_\_ J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c]Z`aZ\_\_ F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c]Z`aZ\_\_ E68E-'(6 J6. bd cdfbbbf`fc cdfbbbfb\fc I:# cb c]Z`aZ\_\_ Q6(-'\* J6. bd S\*:.83 5\*-/ cdfbbbfb\fc (- :&-27 c[bfc^\fbdfc I:# cb c]Z`aZ\_\_ S\*:.83 5\*-/ cdfbbbfadfb (- :&-27 c[bfc^\f`dfc

Finally, the Shiraz router also performs a merge of detour paths in our sample network. The first detour arrives from the Sangiovese router, and the second arrives from Merlot. We see the merged Detour object in the F:(3 message sent by Shiraz to Chardonnay:

I:# cb c]Z`cZdc EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wb^d )-gdecedfd I:# cb c]Z`cZdc D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db]k F\*-(- d I:# cb c]Z`cZdc M-, J6. cb cdfbbbf``fced$d\\_:]c[\ I:# cb c]Z`cZdc C2/6 J6. \ adddd /) I:# cb c]Z`cZdc D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c]Z`cZdc D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c]Z`cZdc C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c]Z`cZdc TQ),68 J6. `\ I:# cb c]Z`cZdc D\*8E-'(6 J6. cb cdfbbbf``fb D I:# cb c]Z`cZdc J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c]Z`cZdc F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c]Z`cZdc E68E-'(6 J6. a^ cdfbbbf``fc cdfbbbf`^fb cdfbbbfcfc cdfbbbfb[fc

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I:# cb c]Z`cZdc Q6(-'\* J6. b\ S\*:.83 5\*-/ cdfbbbf`^fb (- :&-27 c[bfc^\fabfc I:# cb c]Z`cZdc S\*:.83 5\*-/ cdfbbbfb\fc (- :&-27 c[bfc^\fbdfc I:# cb c]Z`cZdc S\*:.83 5\*-/ cdfbbbfadfb (- :&-27 c[bfc^\f`dfc

The Fast Reroute Object The E9'& >5(+%&5 +8057& is contained in F:(3 messages sent along the path of an established LSP. It alerts all downstream routers that the ingress router desires protection along the LSP s path. Each router along the LSP, with the exception of the egress, then creates a detour path around the next downstream node using the Detour object. Information within the Fast Reroute object allows each of the routers to consult a local traffic engineering database for calculating a path to the egress router. This information includes a bandwidth reservation, a hop count, LSP prii ority values, and administrative group knowledge. We discuss the mechanics of fast reroute in greater depth in Chapter 8.

The format of the Fast Reroute object is displayed in Figure 7.18. The field definitions include the following:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object. A constant value of 20 is placed in this field.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The Fast Reroute object falls within the Fast Reroute class, which uses a value of 205.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The Fast Reroute object uses a value of 1 for its CiType.

>5&%\* @(1+(1&! \U +7&5&[ This field contains the priority of the LSP used for assigning resources during its establishment in the network. Possible values range from 0 through 7, with 0 reprei senting the strongest priority value and 7 the weakest priority value. The JUNOS software uses a setup priority value of 7 by default.

G+.6 @(1+(1&! \U +7&5&[ This field contains the priority of the LSP used for maintaining resources after becoming established in the network. Possible values range from 0 through 7, with 0 representing the strongest priority value and 7 the weakest priority value. The JUNOS software uses a hold priority value of 0 by default.

G+\* D1-1& \U +7&5&[ This field displays the total number of transit hops a detour path may take through the network, excluding the local repair node and any router performing a detour merge operation. For example, a hop limit value of 2 means that the detour can leave the local repair node and transit two other routers before being merged or reaching the egress router.

?5'5($56 \U +7&5&[ This field is not used and is set to a constant value of 0x00.

M9,6#16&2 \R +7&5&'[ When populated, this field displays the bandwidth reservation (in bytes per second) that should be performed for all detour paths. By default, the JUNOS software places a value of 0 in this field. @ou may alter this default by configuring a bandwidth within the 5:)(g\*6\*-'(6 definition of the LSP.

F,7.%65 N,! \R +7&5&'[ This field contains information pertaining to network links that are assigned a particular administrative group. When a group value is placed in this field, each network

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link along the detour path must be assigned to that group. A value of 0 in this field means that no group values are required and that all network links may be used.

J"7.%65 N,! \R +7&5&'[ This field contains information pertaining to network links that are assigned a particular administrative group. When a group value is placed in this field, each neti work link along the detour path must ,+& be assigned to that group. A value of 0 in this field means that any network link may be used.

C@B69D LTRK The Fast Reroute object

Using the sample network shown in Figure 7.17 as a guide, we examine the F:(3 message generated by the Sherry router for the \*&'"" , $,+&)" LSP:

I:# cb c]Z`cZdc EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wb`` 46gdebedfd I:# cb c]Z`cZdc D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db]k F\*-(- d I:# cb c]Z`cZdc M-, J6. cb cdfbbbfb[fced$d\\_b\b^` I:# cb c]Z`cZdc C2/6 J6. \ adddd /) I:# cb c]Z`cZdc D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c]Z`cZdc D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c]Z`cZdc C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c]Z`cZdc TQ),68 J6. `\ I:# cb c]Z`cZdc D\*8E-'(6 J6. b\ cdfbbbfb[fb D cdfbbbfcfb D cdfbbbf`\_fb D I:# cb c]Z`cZdc J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c]Z`cZdc F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c]Z`cZdc E68E-'(6 J6. cb cdfbbbfb[fc I:# cb c]Z`cZdc O:)(E6\*-'(6 J6. bd F\*2-l]hdk M-, ^ S@ d9,) I:# cb c]Z`cZdc L.80'76 d$dddddddd P$80'76 d$dddddddd

The O:)(E6\*-'(6 output displays the information contained in the Fast Reroute object. The default setup (7) and hold (0) priority values are requested, and the hop limit is set to 6 hops. No bandwidth reservation is assigned to the detour paths, and all possible links in the network are usable by the detours. This is revealed by examining the L.80'76 and P$80'76 fields and finding all zero values.

32 bits

8 8 8 8

Object Length Class Number CCType Value Setup Priority Hold Priority

Hop Limit Reserved Bandwidth Include Any Exclude Any

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The LSP]Tunnel Session Attribute Object The B=?O<%,,5. =5''1+, J&&(18%&5 +8057& is contained in a F:(3 message and is used by the ingress router to advertise the priority values associated with the LSP. In addition, the name of the RSVP session is included in the object, which allows for easier troubleshooting on transit and egress routers. Finally, information concerning the operation of the LSP and its resource reservations is contained here as well. Figure 7.19 displays the format of the Session Attribute object, which includes the following fields:

A8057& D5,3&2 \T +7&5&'[ This field displays the total length of the RSVP object.

L.9'' B%-85( \U +7&5&[ The value that represents the object s class is placed into this field. The LSPiTunnel Session Attribute object falls within the Session Attribute class, which uses a value of 207.

LY=!\*5 ;9.%5 \U +7&5&[ The specific type of object within its overall class is displayed in this field. The LSPiTunnel Session Attribute object uses a value of 7 for its CiType.

>5&%\* @(1+(1&! \U +7&5&[ This field contains the priority of the LSP used for assigning resources during its establishment in the network. Possible values range from 0 through 7, with 0 reprei senting the strongest priority value and 7 the weakest priority value. The JUNOS software uses a setup priority value of 7 by default.

G+.6 @(1+(1&! \U +7&5&[ This field contains the priority of the LSP used for maintaining resources after becoming established in the network. Possible values range from 0 through 7, with 0 representing the strongest priority value and 7 the weakest priority value. The JUNOS software uses a hold priority value of 0 by default.

I.93' \U +7&5&[ This field contains flags that alert other routers in the network about the capai bilities of the LSP and its resource reservations. Currently, five flag values are defined:

M1& V This flag bit, 0x01, is set to permit downstream routers to use a local repair mechai nism, such as fast reroute link protection, allowing transit routers to alter the explicit route of the LSP.

M1& U This flag bit, 0x02, is set to request that label recording be performed along the LSP path. This means that each downstream node should place its assigned label into the Record Route object in the E6)& message.

M1& T This flag bit, 0x04, is set to indicate that the egress router should use the Shared Explicit reservation style for the LSP. This allows the ingress router to reroute the primary path of the LSP without first releasing the LSP s resources.

M1& S This flag bit, 0x08, is set to indicate that each router along the LSP should reserve bandi width for its fast reroute detour path. The detour paths in the network use this bit value only when the Fast Reroute object is omitted from the F:(3 message created by the ingress router.

M1& R This flag bit, 0x10, is set to permit downstream routers to use a node repair mechai nism, such as fast reroute node protection. Each router should then calculate a detour path that protects the LSP from a failure of the next downstream node.

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B9-5 D5,3&2 \U +7&5&[ This field displays the length of the Session Name field that follows.

>5''1+, B9-5 \;9(198.5[ This variableilength field contains the configured ASCII name of the LSP. Its inclusion in a F:(3 message allows each router along the path to display the LSP name in relevant )3-% commands.

C@B69D LTRJ The LSPaTunnel Session Attribute object

The Merlot router is receiving F:(3 messages from Chianti for the \*&'"" , $,+&)" LSP in Figure 7.17. The Session Attribute object appears within the message as so:

I:# cb c]Z`dZ\_c EDAF \*68& F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wb`` )-gdecedfd I:# cb c]Z`dZ\_c D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`db]k F\*-(- d I:# cb c]Z`dZ\_c M-, J6. cb cdfbbbfcfced$d\\_b\d88 I:# cb c]Z`dZ\_c C2/6 J6. \ adddd /) I:# cb c]Z`dZ\_c D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# cb c]Z`dZ\_c D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# cb c]Z`dZ\_c C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# cb c]Z`dZ\_c TQ),68 J6. `\ I:# cb c]Z`dZ\_c D\*8E-'(6 J6. bd cdfbbbfcfb D cdfbbbf`\_fb D I:# cb c]Z`dZ\_c J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# cb c]Z`dZ\_c F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# cb c]Z`dZ\_c E68E-'(6 J6. bd cdfbbbfcfc cdfbbbfb[fc I:# cb c]Z`dZ\_c O:)(E6\*-'(6 J6. bd F\*2-l]hdk M-, ^ S@ d9,) I:# cb c]Z`dZ\_c L.80'76 d$dddddddd P$80'76 d$dddddddd

The information within the object informs us that the default JUNOS software setup (7) and hold (0) priority values are used for this LSP and that no flags have been set. In addition, the inclusion of the LSP name allows Merlot to display the string in the output of the )3-% /,0) 0), command:

')6\*UI6\*0-(V &.)" +(,& ,&( L.4\*6)) JDFZ d )6))2-.) C-(:0 d 72),0:#67h B, dh Q-%. d

P4\*6)) JDFZ d )6))2-.)

32 bits

8 8 8 8

Object Length Class Number CCType Value Setup Priority Hold Priority

Flags Name Length Session Name

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C-(:0 d 72),0:#67h B, dh Q-%. d

C\*:.)2( JDFZ c )6))2-.) C- O\*-/ D(:(6 E( D(#06 J:9602. J:960-'( JDF.:/6 c[bfc^\fabfc c[bfc^\fc^fc B, c c OO cddccb a D36\*\*#g(-gR3:\* C-(:0 c 72),0:#67h B, ch Q-%. d

RSVP Sessions

When an LSP is established in the network, it is assigned certain resources, including a label value and a bandwidth reservation when it s requested. In addition, the use of fast reroute for the LSP means that each detour path created in the network needs to be associated with the proi tected LSP. All of this information is connected by a common set of data referred to as an >=:? '5''1+,. Specifically, a session is identified by the unique combination of information in F:(3 and E6)& message objects. Within a F:(3 message, the Session, SenderiTemplate, and Session Attribute objects define a session, while the Session and FilteriSpec objects are used in a E6)& message.

The Sherry router is currently the ingress router for an LSP in an MPLS network. It generates the following F:(3 message and forwards it to the first transit router in the path:

I:# ca caZbdZad EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wb`` 46gdebedfd I:# ca caZbdZad D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`da[k F\*-(- d I:# ca caZbdZad M-, J6. cb cdfbbbfb[fced$d\\_b\b^` I:# ca caZbdZad C2/6 J6. \ adddd /) I:# ca caZbdZad D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# ca caZbdZad D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# ca caZbdZad C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# ca caZbdZad TQ),68 J6. `\ I:# ca caZbdZad D\*8E-'(6 J6. b\ cdfbbbfb[fb D cdfbbbfcfb D cdfbbbf`\_fb D I:# ca caZbdZad J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# ca caZbdZad F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# ca caZbdZad E68E-'(6 J6. cb cdfbbbfb[fc I:# ca caZbdZad O:)(E6\*-'(6 J6. bd F\*2-l]hdk M-, ^ S@ d9,) I:# ca caZbdZad L.80'76 d$dddddddd P$80'76 d$dddddddd

The D6))2-.] object defines the egress router address as 192.168.32.1 and assigns a tunnel ID value of 24039 to the LSP. The ingress router information is displayed in the D6.76\*] object, where we see the 192.168.16.1 address and an LSP ID value of 1. The LSP itself is assigned the name \*&'"" , $,+&)", which is contained in the D6))2-.T((\*29'(6 object. This same infori mation is contained in the E6)& message Sherry receives from the next downstream node:

I:# ca caZbdZad EDAF \*68& E6)& cdfbbbfb[fbgVcdfbbbfb[fc J6.Wca^ 46gdebedfd I:# ca caZbdZad D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`da[k F\*-(- d I:# ca caZbdZad M-, J6. cb cdfbbbfb[fbed$d\\_b\b^` I:# ca caZbdZad C2/6 J6. \ adddd /)

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I:# ca caZbdZad D(#06 J6. \ OO I:# ca caZbdZad O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# ca caZbdZad O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# ca caZbdZad J:960 J6. \ cddc`` I:# ca caZbdZad E68E-'(6 J6. b\ cdfbbbfb[fbl50:4Wd$[k I:# ca caZbdZad cdfbbbfcfbl50:4Wd$ck cdfbbbf`\_fb

The egress router address and tunnel ID value are once again contained in the D6))2-.] object. This is the same object data used in the F:(3 message. Information concerning the ingress router is now placed into the O20(6\*] object. Here we see the LSP ID value of 1 assoi ciated with the router address of 192.168.16.1.

The receipt of the E6)& message by Sherry completes the establishment of the LSP. We can view the RSVP session details in the output of the )3-% \*)&, )6))2-. 76(:20 2.4\*6)) comi mand as so:

')6\*UD36\*\*#V &.)" '&#( &1&&-)\* 21%5-, -\*/'1&& L.4\*6)) EDAFZ c )6))2-.)

c[bfc^\fabfc

O\*-/Z c[bfc^\fc^fch JDF)(:(6Z B,h T8(2&6E-'(6Z d JDF.:/6Z D36\*\*#g(-gR3:\*h JDF,:(3Z F\*2/:\*# D'446)(67 0:960 \*6862&67Z gh D'446)(67 0:960 )6.(Z g E68-&6\*# 0:960 \*6862&67Z gh E68-&6\*# 0:960 )6.(Z cddc`` E6)& )(#06Z c OOh J:960 2.Z gh J:960 -'(Z cddc`` C2/6 065(Z gh D2.86Z C'6 I:# ca caZbdZc\ bdda C),68Z \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd F-\*( .'/96\*Z )6.76\* c \*6862&6\* b`da[ ,\*-(-8-0 d O:)(E6\*-'(6 76)2\*67 FTCM \*8&5\*-/Z 0-8:08026.( FTCM )6.((-Z cdfbbbfb[fb l46gdebedfdk c\ ,1() EPDA \*8&5\*-/Z cdfbbbfb[fb l46gdebedfdk bd ,1() P$,08( \*-'(6Z cdfbbbfb[fb cdfbbbfcfb cdfbbbf`\_fb E68-\*7 \*-'(6Z X)605V cdfbbbfb[fb cdfbbbfcfb cdfbbbf`\_fb

Q6(-'\* 2) B, Q6(-'\* FTCM )6.((-Z cdfbbbfb\fb l:(gdecedfdk c] ,1() Q6(-'\* EPDA \*8&5\*-/Z cdfbbbfb\fb l:(gdecedfdk c] ,1() Q6(-'\* P$,08( \*-'(6Z cdfbbbfb\fb cdfbbbf`fb cdfbbbf``fb Q6(-'\* E68-\*7 \*-'(6Z X)605V cdfbbbfb\fb cdfbbbf`fb cdfbbbf``fb Q6(-'\* J:960 -'(Z cddc[b C-(:0 c 72),0:#67h B, ch Q-%. d

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The addresses of the ingress and egress routers are clearly visible in the router output, as is the name of the LSP. The command also displays, however, the ID numbers assigned by Sherry for this session within the F-\*( .'/96\* section. The tunnel ID value of 24039 appears as the \*6862&6\*, while the LSP ID value 1 appears as the )6.76\*. Finally, the ingress router has requested that the LSP be protected through a fast reroute mechanism, as shown by the O:)(E6\*-'(6 desired output. This means that Sherry generates a F:(3 message for the creation of the detour path. When the detour is established, Sherry receives a E6)& message from the first downstream node along the detour. Both of these messages are associated with the original RSVP session through the inclusion of the approi priate objects:

I:# ca caZbdZad EDAF )6.7 F:(3 c[bfc^\fc^fcgVc[bfc^\fabfc J6.Wba^ :(gdecedfd I:# ca caZbdZad D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`da[k F\*-(- d I:# ca caZbdZad M-, J6. cb cdfbbbfb\fced$d\\_b\d88 I:# ca caZbdZad C2/6 J6. \ adddd /) I:# ca caZbdZad D6))2-.T((\*29'(6 J6. b` F\*2- l]hdk 50:4 d$d nD36\*\*#g(-gR3:\*n I:# ca caZbdZad D6.76\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# ca caZbdZad C),68 J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# ca caZbdZad TQ),68 J6. `\ I:# ca caZbdZad D\*8E-'(6 J6. b\ cdfbbbfb\fb D cdfbbbf`fb D cdfbbbf``fb D I:# ca caZbdZad J:960E6+'6)( J6. \ P(36\*C#,6 d$\dd I:# ca caZbdZad F\*-,6\*(26) J6. cb F\*2/:\*# ,:(3 I:# ca caZbdZad E68E-'(6 J6. cb cdfbbbfb\fc I:# ca caZbdZad Q6(-'\* J6. cb S\*:.83 5\*-/ cdfbbbfb\fc (- :&-27 c[bfc^\fbdfc

I:# ca caZbdZa[ EDAF \*68& E6)& cdfbbbfb\fbgVcdfbbbfb\fc J6.Wca^ :(gdecedfd I:# ca caZbdZa[ D6))2-.] J6. c^ c[bfc^\fabfcl,-\*(e('..60 LQ b`da[k F\*-(- d I:# ca caZbdZa[ M-, J6. cb cdfbbbfb\fbed$d\\_b\d88 I:# ca caZbdZa[ C2/6 J6. \ adddd /) I:# ca caZbdZa[ D(#06 J6. \ OO I:# ca caZbdZa[ O0-% J6. a^ \*:(6 d9,) )2"6 d9,) ,6:1 L.59,) / bd I c\_dd I:# ca caZbdZa[ O20(6\*] J6. cb c[bfc^\fc^fcl,-\*(e0), LQ ck I:# ca caZbdZa[ J:960 J6. \ cddc[b I:# ca caZbdZa[ E68E-'(6 J6. b\ cdfbbbfb\fb cdfbbbf`fb cdfbbbf``fb

The Label Distribution Protocol

The second dynamic method of establishing an LSP within the JUNOS software is the B985. G1'O &(18%&1+, ?(+&+7+. (LDP). Unlike the extended version of RSVP, no traffic engineering capabilities are available with LDP, and each labeliswitched path follows the Interior Gateway Protocol (IGP) shortest path through the network. Each LDPispeaking router advertises an address reachable via an MPLS label into the LDP domain. This label information is exchanged by neighbors in a hopi byihop fashion so that every router in the network becomes an ingress router to every other router

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in the network. The end result of this process is a full mesh of LSPs in the domain. Before this can occur, however, each set of adjacent routers forms an LDP neighbor relationship.

Becoming LDP Neighbors

After the protocol is enabled on a local router, it begins sending BG? D5..+ -5''935' on all of its operational interfaces. These messages are addressed to the 224.0.0.2 /32 welliknown destination address and are sent using UDP port 646. The Hello message, as well as all other LDP messages, is encoded using a type, length, value (TLV) paradigm. Each message contains a common LDP header, which is followed by a set of fields describing the message itself. The body of the message contains multiple TLVs, some of which are mandatory, whereas others are optional. Figure 7.20 displays the format of the LDP Hello message, which includes a single mandatory TLV, the hello parameters TLV. The JUNOS software uses two optional TLVs in the Hello message to describe the local router and its properties. The message s fields are as follows:

DK@ ;5('1+, \T +7&5&'[ This field displays the current version of LDP being used by the sendi ing router. It is set to a constant value of 1.

@K< D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the PDU.

DK@ FK \Q +7&5&'[ This field contains a unique LDP ID, which describes the label space used by the local router. The first 4 octets of the ID value represent the advertising node as a unique device in the network. The router ID of the node is placed in this portion of the ID. The final 2 octets of the ID are used to describe the method of label allocation used by the local router. When a perirouter allocation system is in use, as is the JUNOS software default, these octets are set to a value of 0. The LDP ID is displayed in a format of 192.168.1.1:0.

C5''935 =!\*5 \T +7&5&'[ The first bit in this field is defined as the U, or unknown, bit. It is designed as a method for telling routers how to handle a message that is unknown to the local router. When the bit is clear (set to 0), the router must return an error message to the sender if the message type is not recognized. If the bit is set to a value of 1, the local router may ignore the unknown TLV message silently while continuing to process the remainder of the message. For an LDP Hello mesi sage, the U bit is set to a value of 0.

The remaining bits in this field represent the type of message contained in the packet. Hello mesi sages place a constant value of 0x0100 in this field.

C5''935 D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the message.

C5''935 FK \R +7&5&'[ This field contains a 32ibit value generated by the advertising router, which uniquely identifies this particular message.

G5..+ =D; =!\*5 \T +7&5&'[ The first bit in this field is also defined as a U bit. As before, it defines how a receiving router handles an unknown TLV. The hello parameters TLV uses a value of 0 for this bit, requiring all routers to return an error message to the source. The second bit in the field is the F, or forward, bit. It is used only when the U bit is set to a value of 1 and the LDP message is forwarded beyond the receiving router. When the F bit is cleared, the receiving router

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doesn t forward the unknown TLV along with the message. When the F bit is set to a value of 1, the unknown TLV is readvertised along with the LDP message. This bit is not used by the hello parameters TLV and is set to a value of 0.

The remaining bits in this field represent the type code of the TLV. The hello parameters TLV uses a constant value of 0x0400 in this field.

G5..+ =D; D5,3&2 \T +7&5&'[ This field displays the length, in bytes, of the remaining fields in the TLV. The hello parameters TLV uses a constant value of 4 in this field.

G+.6 =1-5 \T +7&5&'[ This field displays the hold time, in seconds, requested by the advertisi ing router. Each set of LDP neighbors negotiates a hold time for their relationship based on the lower value proposed by either neighbor. The JUNOS software uses a hold time of 15 seconds, by default, for all Hello messages.

I.93' 9,6 ?5'5($56 \T +7&5&'[ The first 2 bits in this field, the T and R bits, are designated as flags and are discussed next. The remaining bits in the field are reserved and are set to a constant value of 0.

= M1& The first flag bit, the T bit, encodes the form of hello that the message represents. When the bit is set to a value of 1, the Hello message is a &9(35&56 D5..+. This means that the two LDP neighbors are not directly connected across a network link. A value of 0 for this flag bit means that the Hello message is a .1,/ D5..+ and that the neighbors are directly connected.

? M1& This second flag bit, the R bit, is used when the Hello message is a targeted Hello. When it is set to a value of 1, the local router is requesting that its neighbor respond with its own targeted Hello message. A value of 0 for the flag makes no such request.

A\*&1+,9. =D; =!\*5 \T +7&5&'[ This field contains the type code for any optional TLV used in the message. The JUNOS software uses both an IPv4 transport address TLV (type code of 0x0401) and a configuration sequence number TLV (type code of 0x0402). Both of these TLVs set the U and F flag bits to 0 values.

The use of two TLVs means that the optional type, length, and value fields are repeated multiple times in a single Hello message. The transport address TLV informs the receiving router which address to use when establishing its LDP session with the local router. The configuration sequence number TLV is used by the sending router to alert any receiving routers that configi uration changes have been made to the local router.

A\*&1+,9. =D; D5,3&2 \T +7&5&'[ This field displays the length, in bytes, of the remaining optional TLV fields. Both the IPv4 transport address and configuration sequence number TLVs place a constant value of 4 in this field.

A\*&1+,9. =D; ;9.%5 \;9(198.5[ This variableilength field contains the data carried by each optional TLV. The IPv4 transport address TLV places a 32ibit IP address in this field. By default, the JUNOS software uses the loopback address of the advertising router as the transi port address.

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The configuration sequence number TLV places a value of 1 in this field when LDP is first enabled on the local router. Each committed configuration change prompts the local router to increment this value by 1.

C@B69D LTQS The LDP Hello message

32 bits

8 8 8 8

LDP Version

PDU Length LDP ID LDP ID (continued) Message Type Message Length Message ID Message ID (continued) Hello TLV Type

Hello TLV Length Hold Time Flags and Reserved Optional TLV Type Optional TLV Length Optional TLV Value

Figure 7.21 shows a sample network using LDP for advertising labels and establishing LSPs. Each of the six routers uses OSPF as the IGP, and each has enabled LDP on all of its operational interfaces. On the Chablis router, we see the advertisement of Hello messages to both ?infandel and Cabernet in the output of a (\*:86-,(2-.) file:

I:# ca caZ\_aZc[ JQF )6.( BQF FQB cdfbbbf^dfc gV bb`fdfdfb l)-gdecedfdk I:# ca caZ\_aZc[ &6\* ch ,1( 06. `bh FQB 06. a\h LQ c[bfc^\f\_bfcZd I:# ca caZ\_aZc[ I)4 M600- ld$cddkh 06. b\h LQ c I:# ca caZ\_aZc[ CJA M600-F:\*/) ld$`ddkh 06. ` I:# ca caZ\_aZc[ M-07 (2/6 c\_h 50:4) XV ld$dk I:# ca caZ\_aZc[ CJA ?,-\*(T77\* ld$`dckh 06. ` I:# ca caZ\_aZc[ T77\*6)) c[bfc^\f\_bfc I:# ca caZ\_aZc[ CJA R-.5D6+ ld$`dbkh 06. ` I:# ca caZ\_aZc[ D6+'6.86 c

I:# ca caZ\_aZc[ JQF )6.( BQF FQB cdfbbbf^bfb gV bb`fdfdfb l)-gdececfdk I:# ca caZ\_aZc[ &6\* ch ,1( 06. `bh FQB 06. a\h LQ c[bfc^\f\_bfcZd I:# ca caZ\_aZc[ I)4 M600- ld$cddkh 06. b\h LQ b I:# ca caZ\_aZc[ CJA M600-F:\*/) ld$`ddkh 06. ` I:# ca caZ\_aZc[ M-07 (2/6 c\_h 50:4) XV ld$dk I:# ca caZ\_aZc[ CJA ?,-\*(T77\* ld$`dckh 06. ` I:# ca caZ\_aZc[ T77\*6)) c[bfc^\f\_bfc I:# ca caZ\_aZc[ CJA R-.5D6+ ld$`dbkh 06. ` I:# ca caZ\_aZc[ D6+'6.86 c

Signaling Protocols NSP

C@B69D LTQR LDP sample network

Chardonnay

Cabernet 192.168.32.1

192.168.48.1 10.222.6.0/24 .2 .1

.2

.2 .2

.2

10.222.44.0/24 10.222.45.0/24

10.222.60.0/24 10.222.61.0/24

.1

.1

.1 .1 10.222.46.0/24 10.222.3.0/24

10.222.62.0/24

.1

.2 .2 .1

.1 .2

Shiraz

Merlot

Chablis 192.168.36.1

192.168.40.1

192.168.52.1

The first critical piece of information we notice in the Hello message is contained in the LDP header#the LDP ID. This ID value defines the .985. '\*975 used by the local router as a combination of a unique identifier and the label allocation method used. The LQ c[bfc^\f\_bfcZd router output tells us that Chablis is using its router ID of 192.168.52.1 as its unique identifier. The zero notation at the end of the LDP ID means that Chablis is allocating labels in a perinode fashion, as opposed to a periinterface fashion, which is the JUNOS software default allocation method. This notion of a label space is used when the LDP neighbors form a protocol session between themselves. Only a single session is estabi lished for each label space, regardless of the number of neighbor relationships. A second important piece of information is needed for forming the protocol session, and it is also coni tained in the Hello message. The IPv4 transport address TLV informs the receiving LDP router of the address to be used for the session establishment.

The absence of the IPv4 transport address TLV in a Hello message means that the source address of the message should be used as the transport address.

After each neighbor receives Hello messages from one another, a neighbor relationship is formed between those routers. The )3-% 07, .62439-\* output on the Chablis router shows both the ?infandel (10.222.62.1) and Cabernet (10.222.60.2) routers as active neighbors:

')6\*UR3:902)V &.)" ,2( \*1-/.4)' T77\*6)) L.(6\*5:86 J:960 ),:86 LQ M-07 (2/6 cdfbbbf^dfb )-gdecedfd c[bfc^\f`\fcZd cb cdfbbbf^bfc )-gdececfd c[bfc^\f\_^fcZd cb

Zinfandel 192.168.56.1

NSO Chapter 7 Multiprotocol Label Switching (MPLS)

Establishing LDP Sessions

Once two neighboring LDP routers know each other s label space and transport address via the Hello messages, an BG? '5''1+, is established between those neighbors. This session is used for the advertisement of IPv4 interface addresses, labels, and reachable prefixes across an LSP. For reliable transport of this information, the session is established across a TCP connection between the routers. This TCP connection also uses the LDP welliknown port number of 646 and is initiated by the router with the higher router ID, also known as the 97&1$5 ,+65. Once the neighboring routers can communicate over the TCP transport connection, the active node geni erates and sends an BG? 1,1&19.1 9&1+, -5''935 to its peer, the \*9''1$5 ,+65. This initialization message contains basic information required to establish an LDP session between the neighbors, such as keepalive times and the LDP ID the session is connecting to. The JUNOS software also includes an optional TLV for support of graceful restart capabilities. The format of the LDP inii tialization message is shown in Figure 7.22; the fields are as follows:

DK@ ;5('1+, \T +7&5&'[ This field displays the current version of LDP being used by the sendi ing router. It is set to constant value of 1.

@K< D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the PDU.

DK@ FK \Q +7&5&'[ This field contains the LDP ID of the sending router.

C5''935 =!\*5 \T +7&5&'[ The U bit is set to a value of 0 for all initialization messages. The remaining bits in this field represent the type of message contained in the packet. Initialization messages place a constant value of 0x0200 in this field.

C5''935 D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the message.

C5''935 FK \R +7&5&'[ This field contains a 32ibit value generated by the advertising router that uniquely identifies this particular message.

>5''1+, =D; =!\*5 \T +7&5&'[ Both the U and F bits are set to 0 within the session parameters TLV. The remaining bits in this field represent the type code of the TLV, which is set to a coni stant value of 0x0500 for the session parameters TLV.

>5''1+, =D; D5,3&2 \T +7&5&'[ This field displays the length, in bytes, of the remaining fields in the TLV. The session parameters TLV places a constant value of 14 in this field.

@(+&+7+. ;5('1+, \T +7&5&'[ This field displays the current version of LDP being used by the sending router. It is set to constant value of 1.

G+.6 =1-5 \T +7&5&'[ This field displays the amount of time, in seconds, requested by the adveri tising router as a hold time. Each set of LDP neighbors negotiates a hold time for their relationship based on the lower value proposed by either neighbor. The JUNOS software uses a hold time of 30 seconds, by default. However, the loss of a valid neighbor (using a 15isecond hold time) results in the loss of the LDP session as well.

Signaling Protocols NSN

I.93' 9,6 ?5'5($56 \U +7&5&[ The first 2 bits in this field, the A and D bits, are designated as flags and are discussed next. The remaining bits in the field are reserved and are set to a constant value of 0.

N M1& The first flag bit, the A bit, encodes the method by which the local router advertises MPLS labels to peers. When the bit is cleared and set to 0, the sending router is using G+#,'&(59- ;,'+O .171&56 for advertising labels to peers. This means that the local router may send a label value upstream at any time after the LDP session is established. Setting the A bit to a value of 1 desigi nates that the sending router is using G+#,'&(59- +, G5-9,6 for label advertisement. This requires the upstream router to explicitly request a label mapping before a label is advertised. The JUNOS software uses Downstream Unsolicited, by default, for all LDP sessions.

K M1& This second flag bit, the D bit, is used when loop detection is being used based on advertised path vector TLVs encoded in all LDP messages. A value of 0 signals that loop detection is not enabled on the sending router. A value of 1, on the other hand, means that loop detection is enabled on the sending router. The JUNOS software sets this flag to a 0 value because loop prevention is accomplished through means outside of LDP.

@9&2 ;57&+( D1-1& \U +7&5&[ This field is used to set a limit on the number of hops a message may traverse before a loop is assumed. When loop detection is not used in the network, this field is not used and is set to a constant value of 0x00.

C9"1-%- @K< D5,3&2 \T +7&5&'[ This field allows the LDP neighbors to negotiate the maxi imum PDU length each may transmit across the network link connecting them. This value is a negotiable item, and both neighbors use the lower advertised value. The JUNOS software places a value of 4096 in this field by default.

?5751$5( DK@ FK \Q +7&5&'[ This field contains the LDP ID of the router that is receiving the initialization message. When combined with the LDP ID of the sending router, in the PDU header, this value allows the receiving router to associate the LDP session establishment with an active LDP neighbor.

I9%.& =+.5(9,& =D; =!\*5 \T +7&5&'[ The JUNOS software places the Fault Tolerant TLV in all initialization messages, by default, for support of graceful restart. The U bit is set to a value of 1, while the F bit is left clear. This allows receiving routers to silently ignore the TLV but not forward it along to any other LDP neighbors.

The remaining bits in this field display the type code of the TLV#0x0503. When combined with the settings of the U and F flags, the final TLV type appears as 0x8503.

I9%.& =+.5(9,& =D; D5,3&2 \T +7&5&'[ This field displays the length, in bytes, of the remaining TLV fields. A constant value of 12 is placed in this field.

I9%.& =+.5(9,& I.93' \T +7&5&'[ This field contains numerous flags that describe the state of the faultitolerant restart session. For a full explanation of each flag, please refer to RFC 3479, "Fault Tolerance for the Label Distribution Protocol.!

?5'5($56 \T +7&5&'[ This field is not used and is set to a constant value of 0x0000.

I9%.& =+.5(9,& ?57+,,57& =1-5 \R +7&5&'[ This field displays the amount of time, in milliseci onds, that the sending router maintains control state associated with the restarting router.

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I9%.& =+.5(9,& ?57+$5(! =1-5 \R +7&5&'[ This field displays the maximum amount of time, in milliseconds, that the sending router uses for a restart timer. A value of 0 indicates that the sendi ing router did not maintain the forwarding state throughout the restart event.

C@B69D LTQQ The LDP initialization message

32 bits

8 8 8 8

LDP Version

PDU Length LDP ID LDP ID (continued) Message Type Message Length Message ID Message ID (continued) Session TLV Type Session TLV Length Protocol Version

Hold Time Flags and

Path Vector Reserved

Limit Maximum PDU Length Receiver LDP ID

Receiver LDP ID (continued) Fault Tolerant TLV Type Fault Tolerant TLV Length Fault Tolerant Flags Fault Tolerant Reserved

Fault Tolerant Reconnect Time Fault Tolerant Recovery Time

We ve seen that the Chablis router in Figure 7.21 has active neighbor relationships with both the ?infandel and Cabernet routers. When we focus our attention on just the session establishi ment between Chablis and Cabernet, we find that the Chablis router is the active node for the session because its router ID is higher than Cabernet s. As such, Chablis generates an LDP inii tialization message and forwards it to Cabernet:

I:# ca caZ\_aZa` JQF )6.( CRF FQB c[bfc^\f\_bfc gV c[bfc^\f`\fc l.-.6k I:# ca caZ\_aZa` &6\* ch ,1( 06. \_bh FQB 06. `\h LQ c[bfc^\f\_bfcZd I:# ca caZ\_aZa` I)4 L.2(2:02":(2-. ld$bddkh 06. a\h LQ \ I:# ca caZ\_aZa` CJA D6)F:\*/) ld$\_ddkh 06. c` I:# ca caZ\_aZa` A6\* ch 3-07(2/6 adh 50:4) XV ld$dk I:# ca caZ\_aZa` &68(;02/ dh /:$;,7' `d[^h 27 c[bfc^\f`\fcZd I:# ca caZ\_aZa` CJA N\*:865'0E6)(:\*(F:\*/) ld$\\_dakh 06. cb I:# ca caZ\_aZa` E68-..68( (2/6 d /)h \*68-&6\*# (2/6 d /)

In addition to the negotiable values of hold time and maximum PDU, Chablis includes the LDP ID of Cabernet (192.168.48.1:0) in the message. This allows Cabernet to locate the approi priate neighbor relationship to associate the session with. Once it is located, Cabernet responds to Chablis with its own initialization message:

I:# ca caZ\_aZa` JQF \*8&7 CRF FQB c[bfc^\f`\fc gV c[bfc^\f\_bfc l.-.6k I:# ca caZ\_aZa` &6\* ch ,1( 06. \_bh FQB 06. `\h LQ c[bfc^\f`\fcZd

Signaling Protocols NSL

I:# ca caZ\_aZa` I)4 L.2(2:02":(2-. ld$bddkh 06. a\h LQ \_\_ I:# ca caZ\_aZa` CJA D6)F:\*/) ld$\_ddkh 06. c` I:# ca caZ\_aZa` A6\* ch 3-07(2/6 adh 50:4) XV ld$dk I:# ca caZ\_aZa` &68(;02/ dh /:$;,7' `d[^h 27 c[bfc^\f\_bfcZd I:# ca caZ\_aZa` CJA N\*:865'0E6)(:\*(F:\*/) ld$\\_dakh 06. cb I:# ca caZ\_aZa` E68-..68( (2/6 d /)h \*68-&6\*# (2/6 d /)

This exchange of messages allows the LDP session between the peers to fully establish itself. Cabernet now appears in the output of the )3-% 07, )6))2-. command:

')6\*UR3:902)V &.)" ,2( &1&&-)\*

T77\*6)) D(:(6 R-..68(2-. M-07 (2/6 c[bfc^\f`\fc G,6\*:(2-.:0 G,6. bd c[bfc^\f\_^fc G,6\*:(2-.:0 G,6. b\

The addition of the #" $! option allows us to view additional information pertaining to the established session:

')6\*UR3:902)V &.)" ,2( &1&&-)\* 21%5-, ?8>B?:9B<9B? T77\*6))Z c[bfc^\f`\fch D(:(6Z G,6\*:(2-.:0h R-..68(2-.Z G,6.h M-07 (2/6Z b]

D6))2-. LQZ c[bfc^\f\_bfcZdggc[bfc^\f`\fcZd H6$( 166,:02&6 2. ] )68-.7) T8(2&6h I:$2/'/ FQBZ `d[^h M-07 (2/6Z adh H62439-\* 8-'.(Z c K66,:02&6 2.(6\*&:0Z cdh R-..68( \*6(\*# 2.(6\*&:0Z c J-8:0 :77\*6))Z c[bfc^\f\_bfch E6/-(6 :77\*6))Z c[bfc^\f`\fc B, 5-\* bbZ`\_Zdd J-8:0 g E6)(:\*(Z 72):9067h M60,6\* /-76Z 6.:9067 E6/-(6 g E6)(:\*(Z 72):9067h M60,6\* /-76Z 6.:9067 J-8:0 /:$2/'/ \*68-&6\*# (2/6Z cbdddd /)68 H6$(g3-, :77\*6))6) \*6862&67Z

)-gdecedfd cdfbbbf^fc c[bfc^\f`\fc cdfbbbf^dfb cdfbbbf^cfb

The session between Chablis and Cabernet is currently G,6\*:(2-.:0 with a hold time of 30 seconds. Each router then calculates the timer used to send keepalive messages between the peers to maintain the session. The negotiated hold time of 30 seconds is divided by three, which results in a 10isecond keepalive timer. The receipt of any LDP message within this timer window resets it to the maximum value. When no other messages have been transmitted within the keepalive time, the local router generates an BG? /55\*9.1$5 -5''935 and sends it to the remote peer. Figure 7.23 shows the format of the keepalive message, which includes the following fields:

DK@ ;5('1+, \T +7&5&'[ This field displays the current version of LDP being used by the sendi ing router. It is set to a constant value of 1.

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@K< D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the PDU. It is set to a constant value of 14.

DK@ FK \Q +7&5&'[ This field contains the LDP ID of the sending router.

C5''935 =!\*5 \T +7&5&'[ The U bit is set to a value of 0 for all keepalive messages. The remaini ing bits in this field represent the type of message contained in the packet. Neepalive messages place a constant value of 0x0201 in this field.

C5''935 D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the message. It is set to a constant value of 4.

C5''935 FK \R +7&5&'[ This field contains a 32ibit value generated by the advertising router that uniquely identifies this particular message.

C@B69D LTQP The LDP keepalive message

Exchanging Information Across a Session

Once two LDP peers establish a session between themselves, they begin advertising network knowledge across that session. This information consists of local interface addresses for each peer as well as label values for forwarding MPLS packets through the network. Each set of information uses its own message formats and contains unique information. Let s examine each in further detail.

Advertising Interface Addresses The first set of information transmitted between two LDP peers is the IPv4 interface address for all LDP operational interfaces on the local router. This allows the receiving router to associate future label advertisements with a physical nextihop address for the local router. These addresses are advertised in an BG? 966(5'' -5''935, which is displayed in Figure 7.24. The fields of the message include:

DK@ ;5('1+, \T +7&5&'[ This field displays the current version of LDP being used by the sendi ing router. It is set to a constant value of 1.

@K< D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the PDU.

32 bits

8 8 8 8

LDP Version

PDU Length

LDP ID (continued) Message Type Message Length Message ID Message ID (continued)

LDP ID

Signaling Protocols NSJ

DK@ FK \Q +7&5&'[ This field contains the LDP ID of the sending router.

C5''935 =!\*5 \T +7&5&'[ The U bit is set to a value of 0 for all address messages. The remaini ing bits in this field represent the type of message contained in the packet. Address messages place a constant value of 0x0300 in this field.

C5''935 D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the message.

C5''935 FK \R +7&5&'[ This field contains a 32ibit value generated by the advertising router that uniquely identifies this particular message.

N66(5'' =D; =!\*5 \T +7&5&'[ Both the U and F bits are set to 0 within the address list TLV. The remaining bits in this field represent the type code of the TLV, which is set to a constant value of 0x0101 for the address list TLV.

N66(5'' =D; D5,3&2 \T +7&5&'[ This field displays the length, in bytes, of the remaining fields in the TLV.

N66(5'' I9-1.! \T +7&5&'[ This field displays the type of addresses contained in the TLV. For IPv4 interface addresses, a constant value of 1 is placed in this field.

N66(5'' ;9.%5' \;9(198.5[ This variableilength field displays the interface addresses being advertised by the local router. Each address is encoded as a 32ibit value.

C@B69D LTQO LDP address message

32 bits

8 8 8 8

LDP Version

PDU Length LDP ID LDP ID (continued) Message Type Message Length Message ID Message ID (continued)

Address TLV Type Address TLV Length Address Family Address Values

The LDP session between the Chablis and Cabernet routers in Figure 7.21 can be used to examine the advertisement of addresses associated with those peers. Chablis currently has three addresses that are associated with LDP interfaces. We see those address values transmitted in an address message to Cabernet:

I:# ca caZ\_aZa` JQF )6.( CRF FQB c[bfc^\f\_bfc gV c[bfc^\f`\fc l.-.6k I:# ca caZ\_aZa` &6\* ch ,1( 06. a^h FQB 06. abh LQ c[bfc^\f\_bfcZd I:# ca caZ\_aZa` I)4 T77\*6)) ld$addkh 06. bbh LQ cd I:# ca caZ\_aZa` CJA T77\*J2)( ld$cdckh 06. c`

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I:# ca caZ\_aZa` T77\*6)) 02)(h 5:/20# c I:# ca caZ\_aZa` c[bfc^\f\_bfc I:# ca caZ\_aZa` cdfbbbf^dfc I:# ca caZ\_aZa` cdfbbbf^bfb

These address values represent the loopback interface of Chablis as well as its connections to ?infandel and Cabernet. If Chablis has a requirement for advertising additional interface addresses in the future, it simply generates a new address message containing the new address and sends it to its peers.

From the perspective of the Cabernet router, there are four interface addresses that it needs to send to Chablis. These include the physical network links to Chardonnay, ?infandel, and Chablis as well as its own local loopback interface. The address message containing this infori mation looks like this:

I:# ca caZ\_aZa` JQF \*8&7 CRF FQB c[bfc^\f`\fc gV c[bfc^\f\_bfc l.-.6k I:# ca caZ\_aZa` &6\* ch ,1( 06. `dh FQB 06. a^h LQ c[bfc^\f`\fcZd I:# ca caZ\_aZa` I)4 T77\*6)) ld$addkh 06. b^h LQ \_] I:# ca caZ\_aZa` CJA T77\*J2)( ld$cdckh 06. c\ I:# ca caZ\_aZa` T77\*6)) 02)(h 5:/20# c I:# ca caZ\_aZa` cdfbbbf^fc I:# ca caZ\_aZa` c[bfc^\f`\fc I:# ca caZ\_aZa` cdfbbbf^dfb I:# ca caZ\_aZa` cdfbbbf^cfb

If either of these peers disables LDP on an interface, or the interface is no longer operational, the previously advertised address must be removed from the peer s database. This is accomi plished with an LDP address withdraw message, which is displayed in Figure 7.25. The fields of this message, as well as their meanings, are identical to those described for the address mesi sage. The only difference between the two LDP messages is the message type code value, which is set to 0x0301 for an address withdraw message.

C@B69D LTQN The LDP address withdraw message

32 bits

8 8 8 8

LDP Version

PDU Length LDP ID LDP ID (continued) Message Type Message Length Message ID Message ID (continued)

Address TLV Type Address TLV Length Address Family Address Values

Signaling Protocols NRR

Advertising Label Values The main purpose for using LDP in a network is the establishment of LSPs for forwarding data traffic using MPLS labels. As such, it is critical that we understand how LDP advertises label vali ues to each router in the network. Before discussing this advertisement in detail, however, we first need to examine a concept known as a 4+(#9(61,3 5)%1$9.5,75 7.9'' (FEC). In simple terms, a FEC is a prefix that is mapped by an egress router to an LSP. More specifically, a FEC reprei sents a flow of IP packets through an MPLS network where each packet in the flow is processed identically and forward across the same physical path. For the purposes of our discussion, we ll assume that a FEC represents an IP prefix reachable through the egress router by means of an IP routing table lookup. The egress router then advertises this information upstream to all LDP peers with a specific label value assigned to it. These peers become an ingress router for an LSP that terminates at the egress router. In addition, these peers readvertise the FEC further upstream with a label value allocated locally, making them a transit router in the network. The peers that receive this readvertisement of the FEC then become ingress routers themselves. In this manner, each router in the entire LDP network has a method of forwarding MPLS packets to the FEC advertised by the single egress router. Figure 7.26 shows a FEC advertised by the Chardonnay router and the MPLS forwarding path used by each other router in the network to reach this advertised prefix.

C@B69D LTQM Forwarding equivalence class example

Chardonnay Cabernet

Shiraz Merlot Zinfandel

Chablis

A Juniper Networks router, by default, advertises only its 32ibit loopback address as a FEC. This allows all LDP routers in the network to establish an LSP to the loopback address of every other router in the network, creating a full mesh of LSPs. These MPLSireachable addresses are placed into the 2.6(fa routing table, where the Border Gateway Protocol (BGP) recursive lookup may locate them. The end result is the forwarding of BGP transit traffic across the neti work using labeliswitched paths established by LDP.

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Every prefix advertised as a FEC is associated with a label value allocated by each router along the path of the LSP. This allows label advertisements to proceed in an upstream manner from the egress router to each ingress router without an explicit request for a label. The adveri tisement of a FEC and its label is accomplished with an BG? .985. -9\*\*1,3 -5''935. An indii vidual message may contain a single label and FEC pair or multiple pairs. Figure 7.27 shows the format of the label mapping message, which includes the following fields:

DK@ ;5('1+, \T +7&5&'[ This field displays the current version of LDP being used by the sendi ing router. It is set to a constant value of 1.

@K< D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the PDU.

DK@ FK \Q +7&5&'[ This field contains the LDP ID of the sending router.

C5''935 =!\*5 \T +7&5&'[ The U bit is set to a value of 0 for all label mapping messages. The remaining bits in this field represent the type of message contained in the packet. Label mapping messages place a constant value of 0x0400 in this field.

C5''935 D5,3&2 \T +7&5&'[ This field displays the total length, in bytes, of the remaining fields contained in the message.

C5''935 FK \R +7&5&'[ This field contains a 32ibit value generated by the advertising router that uniquely identifies this particular message.

IJL =D; =!\*5 \T +7&5&'[ Both the U and F bits are set to 0 within the FEC TLV. The remaini ing bits in this field represent the type code of the TLV, which is set to a constant value of 0x0100 for the FEC TLV.

IJL =D; D5,3&2 \T +7&5&'[ This field displays the length, in bytes, of the remaining fields in the TLV.

IJL J.5-5,& =!\*5 \U +7&5&[ This field displays the specific form of the information contained in the FEC TLV. The three defined element types are

:1.679(6 The wildcard FEC element, type code 0x01, is used only to remove previously advertised FEC and label values. It contains no information beyond the FEC element type field.

@(541" The prefix FEC element, type code 0x02, is used by default for all addresses adveri tised by the JUNOS software. It is used to advertise and remove FEC prefixes in the network.

G+'& N66(5'' The host address FEC element, type code 0x03, is used to advertise a comi plete and individual host address into the network.

N66(5'' I9-1.! \T +7&5&'[ This field displays the type of address contained in the FEC TLV. For IPv4 prefixes, a constant value of 1 is placed in this field.

@(541" D5,3&2 \U +7&5&[ This field displays the length of the prefix advertised in the FEC.

IJL @(541" \;9(198.5[ This variableilength field contains the address advertised by the egress router as a FEC.

D985. =D; =!\*5 \T +7&5&'[ Both the U and F bits are set to 0 within the label TLV. The remaining bits in this field represent the type code of the TLV, which is set to a constant value of 0x0200 for the label TLV.

Signaling Protocols NRP

D985. =D; D5,3&2 \T +7&5&'[ This field displays the length, in bytes, of the remaining fields in the TLV. A constant value of 4 is placed in this field.

D985. \R +7&5&'[ This field contains the label value associated with the FEC contained in the FEC TLV.

C@B69D LTQL The LDP label mapping message

32 bits

8 8 8 8

LDP Version

PDU Length LDP ID LDP ID (continued) Message Type Message Length Message ID Message ID (continued) FEC TLV Type

FEC TLV Length FEC Element

Type

Label

Using the LDP session between Chablis and Cabernet in Figure 7.21 as a guide, we see that the Chablis router advertises its loopback address of 192.168.52.1 /32 as a FEC to Cabernet. The label value associated with this prefix is 3, which signals Cabernet to perform PHP when forwarding traffic to this address. The label mapping message containing this information is seen in the output of a (\*:86-,(2-.) file on the Chablis router:

I:# ca caZ\_aZa` JQF )6.( CRF FQB c[bfc^\f\_bfc gV c[bfc^\f`\fc l.-.6k I:# ca caZ\_aZa` &6\* ch ,1( 06. a\h FQB 06. a`h LQ c[bfc^\f\_bfcZd I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ cc I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\f\_bfceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 a

The Cabernet router receives this label mapping message and places it into a local database structure where it is associated with the LDP session it arrived on. Cabernet then allocates a label value from its local set of available labels and readvertises the 192.168.52.1 /32 FEC to all of its LDP peers. This includes the Chablis router, as we see in this router output:

I:# ca caZ\_aZa` JQF \*8&7 CRF FQB c[bfc^\f`\fc gV c[bfc^\f\_bfc l.-.6k I:# ca caZ\_aZa` &6\* ch ,1( 06. a\h FQB 06. a`h LQ c[bfc^\f`\fcZd I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ ^` I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \

Address Family

Address Family (continued)

Prefix Length

FEC Prefix

Label TLV Type Label TLV Length

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I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\f\_bfceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cd`a\_b

In addition to its local FEC of 192.168.48.1 /32, the Cabernet router has received FEC adveri tisements for each of the other routers in the network#?infandel, Merlot, Shiraz, and Chari donnay. After allocating labels for each of the FECs, Cabernet advertises these prefixes to Chablis. Each individual FEC and label pair is encoded in a separate label mapping message contained in a single LDP PDU:

I:# ca caZ\_aZa` JQF \*8&7 CRF FQB c[bfc^\f`\fc gV c[bfc^\f\_bfc l.-.6k I:# ca caZ\_aZa` &6\* ch ,1( 06. c\_dh FQB 06. c`^h LQ c[bfc^\f`\fcZd I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ \_\ I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\f`\fceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 a I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ \_[ I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\fabfceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cd`b\\ I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ ^d I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\fa^fceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cd`ad` I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ ^c I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\f`dfceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cd`abd I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ ^b I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\f\_^fceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cd`aa^

As we saw earlier, Chablis receives these messages and stores them locally in a database. It then allocates labels for each of the FECs and advertises them to all LDP peers, including Cabernet:

I:# ca caZ\_aZa` JQF )6.( CRF FQB c[bfc^\f\_bfc gV c[bfc^\f`\fc l.-.6k I:# ca caZ\_aZa` &6\* ch ,1( 06. c\_dh FQB 06. c`^h LQ c[bfc^\f\_bfcZd

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I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ cb I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\f`\fceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cddddd I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ ca I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\fabfceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cdddc^ I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ c` I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\fa^fceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cdddab I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ c\_ I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\f`dfceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cddd`\ I:# ca caZ\_aZa` I)4 J:960I:, ld$`ddkh 06. b`h LQ c^ I:# ca caZ\_aZa` CJA OPR ld$cddkh 06. \ I:# ca caZ\_aZa` F\*652$h 5:/20# ch c[bfc^\f\_^fceab I:# ca caZ\_aZa` CJA J:960 ld$bddkh 06. ` I:# ca caZ\_aZa` J:960 cddd^`

The end result of this flooding is that each LDP router in the network receives a label from each LDP peer for every possible advertised FEC. This information is stored locally on each router within an BG? 69&989'5 associated with each peering session. The database displays the labelitoiFEC mappings it has received from that peer, as well as the labelitoiFEC mappings it advertised to the peer. For the ChablisiCabernet peering session, we find the following output on the Chablis router:

')6\*UR3:902)V &.)" ,2( 25%545&1 &1&&-)\* ?8>B?:9B<9B? L.,'( 0:960 7:(:9:)6h c[bfc^\f\_bfcZdggc[bfc^\f`\fcZd

J:960 F\*652$ cd`b\\ c[bfc^\fabfceab cd`ad` c[bfc^\fa^fceab cd`abd c[bfc^\f`dfceab a c[bfc^\f`\fceab cd`a\_b c[bfc^\f\_bfceab cd`aa^ c[bfc^\f\_^fceab

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G'(,'( 0:960 7:(:9:)6h c[bfc^\f\_bfcZdggc[bfc^\f`\fcZd

J:960 F\*652$ cdddc^ c[bfc^\fabfceab cdddab c[bfc^\fa^fceab cddd`\ c[bfc^\f`dfceab cddddd c[bfc^\f`\fceab a c[bfc^\f\_bfceab cddd^` c[bfc^\f\_^fceab

At this point in our discussion, you might be worried about forwarding loops in the network. After all, if every router is going to advertise a label for every possible FEC, what prevents Chai blis from forwarding a packet to Cabernet, which would forward it to ?infandel, which would send it back to Chablis? The answer is quite simple really: LDP relies on the loopiprevention mechanisms of the network s IGP. The address of each received FEC is compared against the routing table of the router to verify that it currently has a valid physical next hop. This nextihop interface is then correlated to an LDP peering session based on the interface addresses received in the LDP address messages. Once the appropriate peering session is located, the local router takes the label value advertised over that session and places it, along with the FEC, in the 2.6(fa routing table. The end result of this process is that the LSP from each ingress router to each egress router follows the IGP shortest path through the network.

This method of loop prevention requires that each address advertised in a FEC be reachable via the IGP before being readvertised across other LDP sessions.

We can verify this process by examining information on the Chablis router a bit closer. The current set of loopback addresses contained in the routing table looks like this:

')6\*UR3:902)V &.)" ')$%1 ?8>B?:9A?: %1'&1 (')%)3), )&(0

2.6(fdZ bc 76)(2.:(2-.)h ba \*-'(6) lbc :8(2&6h d 3-077-%.h d 32776.k i W T8(2&6 E-'(6h g W J:)( T8(2&6h j W S-(3

T Q6)(2.:(2-. F F\*5 I6(\*28 c I6(\*28 b H6$( 3-, TD ,:(3 j c[bfc^\fabfceab G cd b V)-gdecedfd j c[bfc^\fa^fceab G cd a V)-gdecedfd )-gdececfd j c[bfc^\f`dfceab G cd b V)-gdececfd j c[bfc^\f`\fceab G cd c V)-gdecedfd j c[bfc^\f\_^fceab G cd c V)-gdececfd

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When we compare this output to the information contained in the 2.6(fa routing table, we see that Chablis uses the same outgoing interface to reach each of the advertised FECs:

')6\*UR3:902)V &.)" ')$%1 %54,1 -\*1%B= %1'&1

2.6(faZ \_ 76)(2.:(2-.)h \_ \*-'(6) l\_ :8(2&6h d 3-077-%.h d 32776.k i W T8(2&6 E-'(6h g W J:)( T8(2&6h j W S-(3

T Q6)(2.:(2-. F F\*5 I6(\*28 c I6(\*28 b H6$( 3-, TD ,:(3 j c[bfc^\fabfceab J [ c V)-gdecedfd j c[bfc^\fa^fceab J [ c )-gdecedfd V)-gdececfd j c[bfc^\f`dfceab J [ c V)-gdececfd j c[bfc^\f`\fceab J [ c V)-gdecedfd j c[bfc^\f\_^fceab J [ c V)-gdececfd

The exception in this example is the 192.168.36.1 /32 route. This route has two equalacost loopafree paths through the network. This allows each routing table to make its own selection for placement in the forwarding table. In our sample output, each table has selected a separate interface.

When an LDP router needs to remove a label and FEC that it had previously announced to a peer, it sends an BG? .985. #1&26(9# -5''935 to that peer. This message is displayed in Figure 7.28, and it uses the same fields as the label mapping message. The main difference between the two messages is the type code used for the label withdraw message#0x0402.

C@B69D LTQK The LDP label withdraw message

32 bits

8 8 8 8

LDP Version

PDU Length LDP ID LDP ID (continued) Message Type Message Length Message ID Message ID (continued) FEC TLV Type

FEC TLV Length FEC Element

Type

Label

Address Family

Address Family (continued)

Prefix Length

FEC Prefix

Label TLV Type Label TLV Length

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Using LDP through an RSVP Network

Some network administrators prefer using LDP for the establishment of LSPs but sometimes find a requirement to trafficiengineer their MPLS traffic. To address this situation, the JUNOS software permits the establishment of an LDP session across an RSVP network by tunneling the LDP traffic within RSVPibased LSPs. This type of network design is referred to as BG? &%,,5.O 1,3 and requires two RSVP signaled labeliswitched paths to exist between the LDP neighbors# one in each direction.

C@B69D LTQJ LDP tunneling

Shiraz

Merlot 192.168.36.1

192.168.40.1

Sangiovese

Zinfandel 192.168.24.1 192.168.56.1

Sherry

Cabernet 192.168.16.1

192.168.48.1

Figure 7.29 shows a network with two physically separated groups of LDP routers. The Sherry, Chianti, and Sangiovese routers are all LDP neighbors, as are the Chablis, Cabernet, and ?infandel routers. We can verify the currently established LDP sessions in the network on the Sangiovese and ?infandel routers:

')6\*UD:.42-&6)6V &.)" ,2( &1&&-)\*

T77\*6)) D(:(6 R-..68(2-. M-07 (2/6

Chianti 192.168.20.1

Chablis 192.168.52.1

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c[bfc^\fc^fc G,6\*:(2-.:0 G,6. b^ c[bfc^\fbdfc G,6\*:(2-.:0 G,6. b^

')6\*U>2.5:.760V &.)" ,2( &1&&-)\*

T77\*6)) D(:(6 R-..68(2-. M-07 (2/6 c[bfc^\f`\fc G,6\*:(2-.:0 G,6. b\_ c[bfc^\f\_bfc G,6\*:(2-.:0 G,6. b[

The administrators of the network would like to forward user traffic from Cabernet to Sherry using MPLS labels. While this is easily accomplished by enabling LDP on the Shiraz and Merlot routers, the network requirement also calls for the engineering of traffic flows across the portion of the network already running RSVP. The solution to this administrative decision is to establish an LDP session between Sangiovese and ?infandel using LDP tunneling. The first step in enabling this session is the creation of RSVPibased LSPs between the two remote LDP routi ers. These LSPs are currently operational across the RSVP core of the network:

')6\*U>2.5:.760V &.)" +(,& ,&( L.4\*6)) JDFZ c )6))2-.) C- O\*-/ D(:(6 E( T8(2&6F:(3 F JDF.:/6 c[bfc^\fb`fc c[bfc^\f\_^fc B, d j 5\*-/g>2.5:.760 C-(:0 c 72),0:#67h B, ch Q-%. d

P4\*6)) JDFZ c )6))2-.) C- O\*-/ D(:(6 E( D(#06 J:9602. J:960-'( JDF.:/6 c[bfc^\f\_^fc c[bfc^\fb`fc B, d c OO a g 5\*-/gD:.42-&6)6 C-(:0 c 72),0:#67h B, ch Q-%. d

C\*:.)2( JDFZ d )6))2-.) C-(:0 d 72),0:#67h B, dh Q-%. d

The second step in forming an LDP session between the two remote routers is the application of the 07,g('..602.4 command to the RSVPibased LSPs:

=672( ,\*-(-8-0) /,0)< ')6\*U>2.5:.760m &1% ,541,C&"-%3.12C(5%. 0')+C6-\*05\*21, ,2(C%$\*\*1,-\*/

=672( ,\*-(-8-0) /,0)< ')6\*UD:.42-&6)6m &1% ,541,C&"-%3.12C(5%. 0')+C75\*/-)#1&1 ,2(C%$\*\*1,-\*/

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Once we commit our configurations, both Sangiovese and ?infandel begin sending LDP tari geted Hello messages to each other through the LSPs. These messages are sent to the address of the RSVP egress router, as seen on the Sangiovese router:

I:# c\_ cdZ\_`Z\_\_ JQF )6.( BQF FQB c[bfc^\fb`fc gV c[bfc^\f\_^fc l0-dfdk I:# c\_ cdZ\_`Z\_\_ &6\* ch ,1( 06. `bh FQB 06. a\h LQ c[bfc^\fb`fcZd I:# c\_ cdZ\_`Z\_\_ I)4 M600- ld$cddkh 06. b\h LQ ]^\ I:# c\_ cdZ\_`Z\_\_ CJA M600-F:\*/) ld$`ddkh 06. ` I:# c\_ cdZ\_`Z\_\_ M-07 (2/6 c\_h 50:4) XC:\*4 E6+C:\*4V ld$8dddk I:# c\_ cdZ\_`Z\_\_ CJA ?,-\*(T77\* ld$`dckh 06. ` I:# c\_ cdZ\_`Z\_\_ T77\*6)) c[bfc^\fb`fc I:# c\_ cdZ\_`Z\_\_ CJA R-.5D6+ ld$`dbkh 06. ` I:# c\_ cdZ\_`Z\_\_ D6+'6.86 \_

The flags set in the Hello message mark this as a targeted Hello and request that the receiving router respond with its own targeted Hello message. Since ?infandel has an established RSVP LSP that egresses at Sangiovese and the LSP is configured for 07,g('..602.4, a targeted Hello is returned by ?infandel:

I:# c\_ cdZ\_`Z\_] JQF \*8&7 BQF FQB c[bfc^\f\_^fc gV c[bfc^\fb`fc l0-dfdk I:# c\_ cdZ\_`Z\_] &6\* ch ,1( 06. `bh FQB 06. a\h LQ c[bfc^\f\_^fcZd I:# c\_ cdZ\_`Z\_] I)4 M600- ld$cddkh 06. b\h LQ c^^d]a I:# c\_ cdZ\_`Z\_] CJA M600-F:\*/) ld$`ddkh 06. ` I:# c\_ cdZ\_`Z\_] M-07 (2/6 c\_h 50:4) XC:\*4 E6+C:\*4V ld$8dddk I:# c\_ cdZ\_`Z\_] CJA ?,-\*(T77\* ld$`dckh 06. ` I:# c\_ cdZ\_`Z\_] T77\*6)) c[bfc^\f\_^fc I:# c\_ cdZ\_`Z\_] CJA R-.5D6+ ld$`dbkh 06. ` I:# c\_ cdZ\_`Z\_] D6+'6.86 \_

At this point, the LDP neighbor relationship is formed and the routers exchange LDP initiali ization messages. The end result of the process is an LDP session between the routers and the exchange of label information:

')6\*UD:.42-&6)6V &.)" ,2( &1&&-)\*

T77\*6)) D(:(6 R-..68(2-. M-07 (2/6 c[bfc^\fc^fc G,6\*:(2-.:0 G,6. b\_ c[bfc^\fbdfc G,6\*:(2-.:0 G,6. b\_ c[bfc^\f\_^fc G,6\*:(2-.:0 G,6. b`

')6\*UD:.42-&6)6V &.)" ,2( \*1-/.4)' T77\*6)) L.(6\*5:86 J:960 ),:86 LQ M-07 (2/6 c[bfc^\f\_^fc 0-dfd c[bfc^\f\_^fcZd ca cdfbbbfb\fc :(gdecedfd c[bfc^\fc^fcZd cb

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cdfbbbfadfb )-gdebedfd c[bfc^\fbdfcZd cc

')6\*UD:.42-&6)6V &.)" ,2( 25%545&1 &1&&-)\* ?8>B?:9B;:B? L.,'( 0:960 7:(:9:)6h c[bfc^\fb`fcZdggc[bfc^\f\_^fcZd

J:960 F\*652$ cd\`\d c[bfc^\fc^fceab cd\`[^ c[bfc^\fbdfceab cd\`^` c[bfc^\fb`fceab cd\`ab c[bfc^\f`\fceab cd\``\ c[bfc^\f\_bfceab a c[bfc^\f\_^fceab

G'(,'( 0:960 7:(:9:)6h c[bfc^\fb`fcZdggc[bfc^\f\_^fcZd

J:960 F\*652$ cdda\_b c[bfc^\fc^fceab cdda^\ c[bfc^\fbdfceab a c[bfc^\fb`fceab cdda\` c[bfc^\f`\fceab cdd`dd c[bfc^\f\_bfceab cdd`c^ c[bfc^\f\_^fceab

The use of the 0-dfd interface for the neighbor relationship across the RSVP LSP requires running LDP on the loopback interface of the peering routers.

Once the session between Sangiovese and ?infandel is established, the Cabernet router receives a FEC for the loopback address of Sherry. This address, as well as the label mapping information from ?infandel, is placed into the 2.6(fa routing table:

')6\*UR:96\*.6(V &.)" ')$%1 %54,1 -\*1%B= ?8>B?:9B?:B?

2.6(faZ \_ 76)(2.:(2-.)h \_ \*-'(6) l\_ :8(2&6h d 3-077-%.h d 32776.k i W T8(2&6 E-'(6h g W J:)( T8(2&6h j W S-(3

c[bfc^\fc^fceab j=JQFe[< ddZacZ\_bh /6(\*28 c

V &2: )-gdecedfdh F')3 cd\`\d

This table entry allows Cabernet to push a label value of 108,480 onto a packet and forward it out its )-gdfcfdfd interface to the ?infandel router. ?infandel should, in turn, forward the packet to its LDP peer of Sangiovese that advertised a label value of 100,352 for that FEC:

')6\*U>2.5:.760V &.)" ,2( 25%545&1 &1&&-)\* ?8>B?:9B><B? L.,'( 0:960 7:(:9:)6h c[bfc^\f\_^fcZdggc[bfc^\fb`fcZd

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J:960 F\*652$ cdda\_b c[bfc^\fc^fceab cdda^\ c[bfc^\fbdfceab a c[bfc^\fb`fceab cdda\` c[bfc^\f`\fceab cdd`dd c[bfc^\f\_bfceab cdd`c^ c[bfc^\f\_^fceab

G'(,'( 0:960 7:(:9:)6h c[bfc^\f\_^fcZdggc[bfc^\fb`fcZd

J:960 F\*652$ cd\`\d c[bfc^\fc^fceab cd\`[^ c[bfc^\fbdfceab cd\`^` c[bfc^\fb`fceab cd\`ab c[bfc^\f`\fceab cd\``\ c[bfc^\f\_bfceab a c[bfc^\f\_^fceab

Under normal circumstances, ?infandel would swap label 108,480 with 100,352 and fori ward the packet directly to Sangiovese. In this particular case, however, Sangiovese is reachable only across an RSVP LSP. This means that along with performing the swap operation so that Sangiovese receives the label it advertised for the FEC, the ?infandel router must push an addii tional label value onto the stack. This second label value (100,304) was advertised by Merlot for the RSVP LSP that egresses at Sangiovese. This information is contained in the output of the )3-% \*)&, )6))2-. 2.4\*6)) command on ?infandel:

')6\*U>2.5:.760V &.)" '&#( &1&&-)\* -\*/'1&& L.4\*6)) EDAFZ c )6))2-.) C- O\*-/ D(:(6 E( D(#06 J:9602. J:960-'( JDF.:/6 c[bfc^\fb`fc c[bfc^\f\_^fc B, d c OO g cddad` 5\*-/g>2.5:.760 C-(:0 c 72),0:#67h B, ch Q-%. d

This simultaneous swap and push operation on ?infandel is visible by examining the /,0)fd switching table using the #" $! option:

')6\*U>2.5:.760V &.)" ')$%1 %54,1 +(,&B@ 21%5-, 0-\*2 ?@9<9@ cd\`\d lc 6.(\*#h c :..-'.867k jJQF F\*656\*6.86Z [

H6$( 3-,Z &2: )-gdececfd %6243( ch )6068(67 J:960g)%2(8367g,:(3 5\*-/g>2.5:.760 J:960 -,6\*:(2-.Z D%:, cdda\_bh F')3 cddad`l(-,k D(:(6Z XT8(2&6 L.(V T46Z b I6(\*28Z c C:)1Z JQF

Summary NQP

T..-'.86/6.( 92() lckZ dgKEC TD ,:(3Z L F\*652$6) 9-'.7 (- \*-'(6Z c[bfc^\fc^fceab

cd\`[^ lc 6.(\*#h c :..-'.867k jJQF F\*656\*6.86Z [

H6$( 3-,Z &2: )-gdececfd %6243( ch )6068(67 J:960g)%2(8367g,:(3 5\*-/g>2.5:.760 J:960 -,6\*:(2-.Z D%:, cdda^\h F')3 cddad`l(-,k D(:(6Z XT8(2&6 L.(V T46Z b I6(\*28Z c C:)1Z JQF T..-'.86/6.( 92() lckZ dgKEC TD ,:(3Z L F\*652$6) 9-'.7 (- \*-'(6Z c[bfc^\fbdfceab gggl/-\*6kggg=:9-\*(<

The top MPLS label in the stack is swapped by Merlot when it receives the data packet. It is then forwarded to the Shiraz router, which performs a label pop operation and forwards the remaining data to Sangiovese. The packet received by Sangiovese has an MPLS label assigned that Sangiovese advertised as a FEC to ?infandel. This allows the Sangiovese router to recognize the label and perform a label operation on the received packet. In our example, this label operi ation is a pop because the nextihop router, Sherry, is the egress router and requested that Sani giovese perform PHP.

Summary

In this chapter, we examined the Resource Reservation Protocol (RSVP) and how to use it to establish labeliswitched paths. After a discussion of the various RSVP message types, we explored the RSVP objects themselves at great depth. Finally, we discussed the concept of an RSVP session and used )3-% commands to prove the network was operating normally.

We concluded the chapter with a discussion of the Label Distribution Protocol (LDP). After examining how two routers become LDP neighbors, we described the establishment of an LDP session between those peers. Once the session was established, we saw the advertisement of interface addresses, forwarding equivalence classes, and labels between those peers. Finally, we established a session between two physically remote neighbors by tunneling LDP through an RSVPibased LSP.

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Exam Essentials

M5 98.5 &+ 5"\*.91, 2+# 9, ?>;@Y89'56 \*9&2 1' 5'&98.1'256 1, 9, C@D> ,5&#+(/X An MPLS network using RSVP for signaling labeliswitched paths uses F:(3 and E6)& messages for the establishment of the LSP. F:(3 messages are transmitted downstream, whereas E6)& messages are transmitted upstream. Each message enables routers to allocate and maintain protocol state associated with the path.

E,+# &25 ?>;@ -5''935 &!\*5' %'56 1, 9, C@D> ,5&#+(/ 4+( (5-+$1,3 \*(+&+7+. '&9&5X RSVP routers remove protocol state from the network by transmitting F:(3C6:\* and E6)&C6:\* mesi sages. These messages traverse the LSP path in the same direction of their counterparts. F:(3C6:\* messages are transmitted downstream, whereas E6)&C6:\* messages are sent upstream.

M5 98.5 &+ 65'7(185 &25 ?>;@ +8057&' %'56 &+ (+%&5 9, D>@ &2(+%32 &25 ,5&#+(/ 9,6 9..+79&5 .985. 1,4+(-9&1+,X An RSVPibased LSP uses the Explicit Route object to formulate a path through an MPLS network. This allows the LSP to utilize links other than that specified by the IGP shortest path. The actual path used by the LSP is detailed in the Record Route object, which is also used for loop prevention during the LSP establishment phase. Finally, the MPLS labels used to forward traffic through the LSP are assigned using the Label Request and Label objects.

M5 98.5 &+ 65'7(185 2+# ?>;@ '5''1+,' 9(5 165,&14156 1, 9, C@D> ,5&#+(/X Each established labeliswitched path belongs to a specific RSVP session in the network. This session is uniquely identified by information contained in the SenderiTemplate, Session, and Session Attribute objects. Specifically, the address of the egress router, the tunnel ID, and the LSP ID are used to identify the session.

M5 98.5 &+ 65'7(185 2+# DK@ 4+(-' 9 '5''1+, 85&#55, &#+ \*55('X Two neighboring LDP routers first begin exchanging Hello messages with each other. These messages contain the label space advertised by the local router as well as the transport address to be used for the establishi ment of the session. Once each router determines the neighbor on its interface, the peer with the higher transport address becomes the active node. This active node sends initialization messages to the passive node to begin the session setup phase. Once the passive peer returns its own inii tialization message, the session becomes fully established.

<,65('&9,6 2+# 966(5'' 9,6 .985. 1,4+(-9&1+, 1' \*(+\*939&56 1, 9, DK@ ,5&#+(/X After two LDP routers form a session between themselves, they begin advertising their local interface addresses to the peer with address messages. This allows the receiving peer to associate a physi ical next hop with the established session. Once this exchange is completed, the peers advertise reachable prefixes and labels in a label mapping message. The prefixes advertised by each LDP router compose a FEC, which is readvertised throughout the LDP network.

Review Euestions NQN

Review Euestions

1. Which RSVP object appears in both a F:(3 and a E6)& message?

A. Label B. Label Request C. Explicit Route D. Record Route

2. Which RSVP object is used to signal all routers along the LSP to protect against downstream link

and node failures? A. Detour B. Fast Reroute C. Session Attribute D. SenderiTemplate

3. Which RSVP reservation style is used by default within the JUNOS software?

A. Fixed filter B. Wildcard filter C. Shared explicit D. Shared wildcard

4. Which RSVP message removes existing reservation state from routers along the path of an LSP?

A. F:(3C6:\* sent to the ingress router B. E6)&C6:\* sent to the ingress router C. F:(3C6:\* sent to the egress router D. E6)&C6:\* sent to the egress router

5. What three RSVP objects are used to uniquely identify an RSVP session in the network?

A. SenderiTemplate B. SenderiTspec C. Session D. Session Attribute

6. What prompts each MPLS router to examine the contents of an RSVP F:(3 message?

A. The destination address is the local router s interface address. B. The Router Alert option is set in the IP packet header. C. It is sent to a welliknown TCP port number. D. None of the above.

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7. What RSVP object is used to avoid a forwarding loop along the path of an LSP?

A. Explicit Route B. Record Route C. Session Attribute D. Session

8. What is the destination address and protocol information for an LDP Hello message?

A. Destined to 224.0.0.2 and UDP port 646 B. Destined to 224.0.0.2 and TCP port 646 C. Destined to 224.0.0.1 and UDP port 646 D. Destined to 224.0.0.1 and TCP port 646

9. What information does the JUNOS software include by default in the FEC advertised by each router?

A. All IP prefixes located on the local router B. All interface addresses for the local router C. Only subnets through which an LDP neighbor is located D. Only the local router s loopback address

10. How does an LDP network prevent routing and forwarding loops? A. Label information is advertised only between specific peers. B. LDP routers perform a reverse path forwarding check for all packets. C. The shortestipath first calculation is performed against the contents of the LDP database. D. LDP routers use the IGP shortestipath information contained in the routing table.

Answers to Review Euestions NQL

Answers to Review Euestions

1. D. Of the listed RSVP objects, only the Record Route object may appear in both a F:(3 and

a E6)& message. The Explicit Route and Label Request objects appear only in F:(3 messages, whereas the Label object appears only in E6)& messages.

2. B. When included in a F:(3 message, the Fast Reroute object informs each LSP of the ingress

router s desire to protect the LSP against downstream failures. Each node along the LSP path then creates a detour around the downstream resource using a F:(3 message with the Detour object.

3. A. The fixed filter (FF) reservation style is used by default on all RSVP LSPs created by the

JUNOS software.

4. B. Existing reservation state is removed from the network through the use of the E6)&C6:\* message.

This message type is always advertised in a hopibyihop fashion to the ingress router.

5. A, C, D. The unique set of information contained in the SenderiTemplate, Session, and Session

Attribute objects uniquely identifies an RSVP session in the network.

6. B. Within the IP packet header of the RSVP F:(3 message, the Router Alert option is enabled.

This allows each router along the path to examine the contents even though the destination address of the packet is the egress router s address.

7. B. When each RSVP router receives either a F:(3 or a E6)& message, it examines the Record

Route object looking for one of its interface addresses. If it finds one, that means a forwarding loop is in place within the network and the LSP is not established.

8. A. All LDP Hello messages are transmitted to the welliknown UDP port number of 646. In addition,

all link Hellos are sent to the 224.0.0.2 multicast group address representing all routers on the subnet.

9. D. By default, only the loopback address of the local router is advertised as part of the FEC for

that router.

10. D. Routing and forwarding loops are prevented in an LDP network by consulting the shortestipath information in the local routing table. The outgoing interface for a particular route is mapped to the label received from the LDP peer associated with that interface.

Chapter8

H0"3)1/0 =:>8

?<F@8 D4H= ;G?DF7@5D8 F;5D9DE @< 7A@8 FAH:7D9I

Identify the operational steps of the constrained shortest path first algorithm

Describe the extensions to OSPF that support traffic engineering

Describe the extensions to IS]IS that support traffic engineering

Define the reason(s) for configuring the following LSP attributes: primaryO secondaryO administrative groupsO adaptive settingsO priority/preemptionO optimizationO forwarding adjacencies into IGPsO fast rerouteO metricO time]to]live optionsO auto]bandwidthO explicit null

In this chapter, we construct a linkistate database specifically designed for engineering labeliswitched path (LSP) traffic flows. The JUNOS software uses this traffic engineering database (TED) to generate a Resource Reservation Protocol (RSVP) path through the network based on constraints you provide. We discuss the contents of the database and the algorithm used on those contents. We then examine some methods for protecting traffic flows in the Multiprotocol Label Switching (MPLS) network. This discussion centers on providing secondary backup paths across the domain as well as using fast reroute to protect traffic already using the LSP. We conclude the chapter with an exploration of various attributes that affect individual LSPs. We discuss some bandwidth reseri vation options as well as some methods for hiding the physical connectivity of your MPLS network. Finally, we investigate how user data traffic not associated with Border Gateway Protocol (BGP) can use an LSP for forwarding packets across the network.

Constrained Shortest Path First

The ability to engineer LSP traffic flows using RSVP is greatly enhanced through the use of an algorithm known as H+,'&(91,56 =2+(&5'& ?9&2 E1('& (CSPF). This algorithm is a modified version of the SPF algorithm used within the linkistate databases of Open Shortest Path First (OSPF) and Intermediate System to Intermediate System (ISiIS). It operates within a special database, the TED, constructed through extensions to the linkistate protocols themselves. We discuss the basic use of the TED by RSVP, the extensions defined for the interior gateway proi tocols (IGPs), and the steps of the CSPF algorithm itself.

Using the Traffic Engineering Database

The topology of an RSVP network is populated into the TED by the linkistate protocols. This basic network topology includes the devices capable of running MPLS as well as information on bandwidth availability, available priority values, and administrative controls#to name a few. When you define an LSP within the JUNOS software, you have the ability to supply constraints to the ingress router. These useridefined criteria are passed to the CSPF algorithm before it coni sults the information in the TED. The algorithm removes all network links from consideration that don t meet the constraints. It then places the remaining topology data into a temporary data structure. The shortest path between the ingress and egress routers is calculated by the algorithm using this subset of information. The result of the CSPF algorithm is formed into a strictihop Explicit Route object (ERO) detailing each hop along the calculated path. The ERO is passed to the RSVP protocol process, where it is used for signaling and establishing the LSP in the network.

Constrained Shortest Path First NPR

The creation of this ERO does not, however, prevent you from creating your own explicit route via a named path in the JUNOS software. All useridefined path information is passed to the CSPF algorithm as a requested constraint. After creating the subset of network links within the TED, the algorithm consults the information in the useridefined named path. The router runs a separate CSPF calculation to locate the path from the ingress router to the first node listed in the user s ERO. A second CSPF calculation is performed to find a path from the first node to the second node in the user s ERO. The router repeats this pattern of CSPF cali culations until the egress router is reached. The results of the multiple computations are then combined into a single strictihop ERO from the ingress to the egress.

The ability of CSPF to locate a viable network path for an LSP is greatly affected by the infori mation in the TED, so let s investigate how the IGPs propagate this data.

OSPF Traffic Engineering Extensions

The OSPF protocol makes use of a <!\*5 MN @\*9)%5 B=J for advertising traffic engineering information in a network. This LSA type has an area flooding scope, which limits the creation of the TED to a single OSPF area. This means that a large OSPF network with multiple areas will have multiple TEDs, one for each operational area.

Figure 8.1 displays the format of the Opaque LSA used by OSPF for advertising traffic engii neering information. The fields of the LSA include the following:

D1,/Y>&9&5 N35 \T +7&5&'[ The LinkiState Age field displays the time, in seconds, since the LSA was first originated into the network. The age begins at the value 0 and increments to a value of 3600 (1 hour).

A\*&1+,' \U +7&5&[ The local router advertises its capabilities in this field, which also appears in other OSPF packets. The router sets bit 6 in this field, indicating its support for traffic engineering.

D1,/Y>&9&5 =!\*5 \U +7&5&[ This field displays the type of linkistate advertisement (LSA). Opaque LSAs set this field to a constant value of 10.

A\*9)%5 =!\*5 \U +7&5&[ The Opaque LSA specification defines the first octet of the linkistate ID field as the Opaque Type field. When used to support traffic engineering, a constant value of 1 is placed in this field.

?5'5($56 \U +7&5&[ This field is not used and is set to a constant value of 0x00.

F,'&9,75 \T +7&5&'[ The Instance field of a traffic engineering Opaque LSA is used by the local router to support multiple, separate LSAs. By default, the JUNOS software generates one LSA for the router itself as well as a separate LSA for each operational interface.

N6$5(&1'1,3 ?+%&5( \R +7&5&'[ This field displays the router ID of the OSPF device that origii nated the LSA.

D1,/Y>&9&5 >5)%5,75 B%-85( \R +7&5&'[ The sequence number field is a signed 32ibit value used to guarantee that each router in the area has the most recent version of the Opaque LSA.

D1,/Y>&9&5 L257/'%- \T +7&5&'[ This field displays a standard IP checksum for the entire LSA, excluding the LinkiState Age field.

D5,3&2 \T +7&5&'[ This field displays the length of the entire LSA, including the header fields.

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C@B69D KTR Traffic engineering Opaque LSA format

32 bits

8 8 8 8

LinkCState Age Options LinkCState Type Opaque Type Reserved Instance

Advertising Router LinkCState Sequence Number LinkCState Checksum

Length Traffic Engineering Type Traffic Engineering Length

Traffic Engineering Value

=(94417 J,31,55(1,3 =!\*5 \T +7&5&'[ The traffic engineering data is encoded within the Opaque LSA using a type, length, value (TLV) paradigm. Currently two TLV type values are defined. The Router Address TLV uses a type code of 1, whereas the Link TLV uses a type code of 2.

=(94417 J,31,55(1,3 D5,3&2 \T +7&5&'[ This field displays the length, in bytes, of the value pori tion of the TLV.

=(94417 J,31,55(1,3 ;9.%5 \;9(198.5[ This field displays the specific information contained within the TLV being advertised.

The Sherry router is running OSPF and has enabled the traffic engineering extensions by applying the (\*:5528f6.42.66\*2.4 command at the global OSPF level. The configuration of Sherry currently looks like this:

')6\*TC36\*\*#U '0\*# 5\*+2/1%(7&/\*+ )(\*&\*5\*-' \*')2 (\*:5528f6.42.66\*2.4X :\*6: cececec !

2.(6\*5:86 :00X 2.(6\*5:86 5$,cec !

72):906X

This allows the Sherry router to generate traffic engineering Opaque LSAs, which it places into the local linkistate database and floods to all its neighbors:

')6\*TC36\*\*#U '0\*# \*')2 47&767'3 74$3(&/'/+1H(\*%&3( D>CGD@?GD@GD

FCEN 02.1 )(:(6 7:(:9:)6g :\*6: cececec B#,6 KP S7& D(\* C6+ S46 F,( Q1)'/ I6. D-'(6\* ibZaeb][eb]eb bZaeb][eb]eb c$[cccc`\c ^^ c$a c$9:7[ \a G6(%-\*1 ibceceb^ea bZaeb][eb]eb c$[cccc`]^ acb c$a c$989` `a

Constrained Shortest Path First NPP

G6(%-\*1 ibceceb]eb bZaeb][eb]eb c$[cccc`]\_ [cb c$a c$^^a\_ `a F,:+S\*6:ibececeb bZaeb][eb]eb c$[ccccccb ^^ c$a c$9c:Z a[ F,:+S\*6:ibececea bZaeb][eb]eb c$[ccccccb ^c c$a c$Z\_86 ba\_ F,:+S\*6:ibecece` bZaeb][eb]eb c$[ccccccb ^c c$a c$\95b ba\_ F,:+S\*6:ibecece\_ bZaeb][eb]eb c$[ccccccb ^c c$a c$ba\_] ba\_

The LSA whose linkistate ID is currently 1.0.0.1 contains the >+%&5( J66(5'' <B: representi ing the router itself. The TLV uses a type code value of 1 and has a constant length of 4 octets. The value contained in the Router Address TLV includes an IP address that is consistently reachable on the local router. The loopback address of the local router is used for this value, 192.168.16.1 in the case of the Sherry router:

')6\*TC36\*\*#U '0\*# \*')2 47&767'3 -'7H/4 DGEGEGD 43&7/-

FCEN 02.1 )(:(6 7:(:9:)6g :\*6: cececec B#,6 KP S7& D(\* C6+ S46 F,( Q1)'/ I6. F,:+S\*6:ibececeb bZaeb][eb]eb c$[ccccccb ^[ c$a c$9c:Z a[

S\*6:f-,:+'6 BO ICS D(\*S77\* kbjg 06.4(3 \_Y bZaeb][eb]eb

Each of the remaining TLVs advertised by Sherry represents the operational links on the router, and each contains a single B1,/ <B:. The value portion of the TLV contains multiple subiTLVs to describe the traffic engineering capabilities of the interface. The type codes of the defined subiTLVs are

D1,/ =!\*5 The Link Type subiTLV has a type code of 1 and a subiTLV length of 1 octet. The value portion of the subiTLV describes whether the link is a pointitoipoint or broadcast interi face. Pointitoipoint interfaces use a value of 1 in the subiTLV, whereas broadcast interfaces place a 2 in the value portion of the subiTLV.

D1,/ FK The Link ID subiTLV uses a type code of 2 and describes the opposite end of the link. The subiTLV has a length of 4 octets and contains an IP address in the value portion of the subiTLV. For a pointitoipoint link, the router ID of the remote neighbor is encoded in the subiTLV. The interface address of the designated router is placed in the subiTLV for all broadcast interfaces.

D+79. F,&5(4975 F@ N66(5'' The use of the Local Interface IP Address subiTLV is fairly straightforward#it contains the interface address of the local router for the link being described by the Opaque LSA. The subiTLV uses a type code of 3 and has a length of 4 octets.

?5-+&5 F,&5(4975 F@ N66(5'' The Remote Interface IP Address subiTLV contains the interface address of the remote router for the link being described by the Opaque LSA. The subiTLV uses a type code of 4 and has a length of 4 octets. Pointitoipoint interfaces use the remote router s address in this field, whereas broadcast links use a value of 0.0.0.0. When the link is configured as an unnumbered interface, the first 2 octets of the value portion contain all zeros. The remaini ing 2 octets contain a unique interface index value.

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=(94417 J,31,55(1,3 C5&(17 The Traffic Engineering Metric subiTLV has a type code of 5 and a subiTLV length of 4 octets. It contains the metric value of the interface that should be used by the CSPF algorithm. The JUNOS software places the same value in this subiTLV as it places in the Router LSA of the local router.

C9"1-%- M9,6#16&2 The Maximum Bandwidth subiTLV contains the true bandwidth of the local interface in bytes per second. It uses a type code of 6 and has a constant length of 4 octets.

C9"1-%- ?5'5($98.5 M9,6#16&2 The Maximum Reservable Bandwidth subiTLV displays the total amount of bandwidth, in bytes per second, available for reservations by the RSVP proi cess. This value may be larger than the actual bandwidth of the interface to account for overi subscription of the interface. The subiTLV has a type code of 7 and a constant length of 4 octets.

<,(5'5($56 M9,6#16&2 The type code of the Unreserved Bandwidth subiTLV is 8. It displays the amount of bandwidth, in bytes per second, that is currently available for reservations on the local interface. This value is calculated for each of the eight priority levels used by the extensions to the RSVP specification. Each unreserved bandwidth value has a length of 4 octets, which results in the entire subiTLV having a length of 32 octets.

?5'+%(75 L.9''WL+.+( The Resource Class/Color subiTLV has a type code of 9 and a subiTLV length of 4 octets. The value portion of the subiTLV contains a 32ibit vector used to encode membership in various administrative groups. An individual interface may belong to multiple groups, in which case multiple bits are set within the bit vector.

The Sherry router is generating three Opaque LSAs to represent its three operational links in the traffic engineering domain. Here are the contents of one of the LSAs:

')6\*TC36\*\*#U '0\*# \*')2 47&767'3 -'7H/4 DGEGEGC 43&7/-

FCEN 02.1 )(:(6 7:(:9:)6g :\*6: cececec B#,6 KP S7& D(\* C6+ S46 F,( Q1)'/ I6. F,:+S\*6:ibececea bZaeb][eb]eb c$[ccccccb ^` c$a c$Z\_86 ba\_

S\*6:f-,:+'6 BO ICS I2.1 kajg 06.4(3 bccY

I2.1(#,6 kbjg 06.4(3 bY a I2.1KP kajg 06.4(3 \_Y

bceaaaea[ea I-8K5S7\* k`jg 06.4(3 \_Y

bceaaaea[eb D6/K5S7\* k\_jg 06.4(3 \_Y

cececec BOH6(\*28 k^jg 06.4(3 \_Y b H:$R? k]jg 06.4(3 \_Y

bccH9,) H:$D)&R? k\jg 06.4(3 \_Y