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D. Awduche
Movaz Networks, Inc.
L. Berger
D. Gan
Juniper Networks, Inc.
T. Li
Procket Networks, Inc.
V. Srinivasan
Cosine Communications, Inc.
G. Swallow
Cisco Systems, Inc.

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RSVP-TE: Extensions to RSVP for LSP Tunnels

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Abstract

This document describes the use of RSVP (Resource Reservation Protocol), including all the necessary extensions, to establish label-switched paths (LSPs) in MPLS (Multi-Protocol Label Switching). Since the flow along an LSP is completely identified by the label applied at the ingress node of the path, these paths may be treated as tunnels. A key application of LSP tunnels is traffic engineering with MPLS as specified in RFC 2702.

We propose several additional objects that extend RSVP, allowing the establishment of explicitly routed label switched paths using RSVP as a signaling protocol. The result is the instantiation of label-switched tunnels which can be automatically routed away from network failures, congestion, and bottlenecks.

Contents

1. Introduction

Section 2.9 of the MPLS architecture [2] defines a label distribution protocol as a set of procedures by which one Label Switched Router (LSR) informs another of the meaning of labels used to forward traffic between and through them. The MPLS architecture does not assume a single label distribution protocol. This document is a specification of extensions to RSVP for establishing label switched paths (LSPs) in MPLS networks.

Several of the new features described in this document were motivated by the requirements for traffic engineering over MPLS (see [3]). In particular, the extended RSVP protocol supports the instantiation of explicitly routed LSPs, with or without resource reservations. It also supports smooth rerouting of LSPs, preemption, and loop detection.

The LSPs created with RSVP can be used to carry the "Traffic Trunks" described in [3]. The LSP which carries a traffic trunk and a traffic trunk are distinct though closely related concepts. For example, two LSPs between the same source and destination could be load shared to carry a single traffic trunk. Conversely several

traffic trunks could be carried in the same LSP if, for instance, the LSP were capable of carrying several service classes. The applicability of these extensions is discussed further in [10].

Since the traffic that flows along a label-switched path is defined by the label applied at the ingress node of the LSP, these paths can be treated as tunnels, tunneling below normal IP routing and filtering mechanisms. When an LSP is used in this way we refer to it as an LSP tunnel.

LSP tunnels allow the implementation of a variety of policies related to network performance optimization. For example, LSP tunnels can be automatically or manually routed away from network failures, congestion, and bottlenecks. Furthermore, multiple parallel LSP tunnels can be established between two nodes, and traffic between the two nodes can be mapped onto the LSP tunnels according to local policy. Although traffic engineering (that is, performance optimization of operational networks) is expected to be an important application of this specification, the extended RSVP protocol can be used in a much wider context.

The purpose of this document is to describe the use of RSVP to establish LSP tunnels. The intent is to fully describe all the objects, packet formats, and procedures required to realize interoperable implementations. A few new objects are also defined that enhance management and diagnostics of LSP tunnels.

The document also describes a means of rapid node failure detection via a new HELLO message.

All objects and messages described in this specification are optional with respect to RSVP. This document discusses what happens when an object described here is not supported by a node.

Throughout this document, the discussion will be restricted to unicast label switched paths. Multicast LSPs are left for further study.

1.1. Background

Hosts and routers that support both RSVP [1] and Multi-Protocol Label Switching [2] can associate labels with RSVP flows. When MPLS and RSVP are combined, the definition of a flow can be made more flexible. Once a label switched path (LSP) is established, the traffic through the path is defined by the label applied at the ingress node of the LSP. The mapping of label to traffic can be accomplished using a number of different criteria. The set of packets that are assigned the same label value by a specific node are

said to belong to the same forwarding equivalence class (FEC) (see [2]), and effectively define the "RSVP flow." When traffic is mapped onto a label-switched path in this way, we call the LSP an "LSP Tunnel". When labels are associated with traffic flows, it becomes possible for a router to identify the appropriate reservation state for a packet based on the packet's label value.

The signaling protocol model uses downstream-on-demand label distribution. A request to bind labels to a specific LSP tunnel is initiated by an ingress node through the RSVP Path message. For this purpose, the RSVP Path message is augmented with a LABEL_REQUEST object. Labels are allocated downstream and distributed (propagated upstream) by means of the RSVP Resv message. For this purpose, the RSVP Resv message is extended with a special LABEL object. The procedures for label allocation, distribution, binding, and stacking are described in subsequent sections of this document.

The signaling protocol model also supports explicit routing capability. This is accomplished by incorporating a simple EXPLICIT_ROUTE object into RSVP Path messages. The EXPLICIT_ROUTE object encapsulates a concatenation of hops which constitutes the explicitly routed path. Using this object, the paths taken by label-switched RSVP-MPLS flows can be pre-determined, independent of conventional IP routing. The explicitly routed path can be administratively specified, or automatically computed by a suitable entity based on QoS and policy requirements, taking into consideration the prevailing network state. In general, path computation can be control-driven or data-driven. The mechanisms, processes, and algorithms used to compute explicitly routed paths are beyond the scope of this specification.

One useful application of explicit routing is traffic engineering. Using explicitly routed LSPs, a node at the ingress edge of an MPLS domain can control the path through which traffic traverses from itself, through the MPLS network, to an egress node. Explicit routing can be used to optimize the utilization of network resources and enhance traffic oriented performance characteristics.

The concept of explicitly routed label switched paths can be generalized through the notion of abstract nodes. An abstract node is a group of nodes whose internal topology is opaque to the ingress node of the LSP. An abstract node is said to be simple if it contains only one physical node. Using this concept of abstraction, an explicitly routed LSP can be specified as a sequence of IP prefixes or a sequence of Autonomous Systems.

The signaling protocol model supports the specification of an explicit path as a sequence of strict and loose routes. The combination of abstract nodes, and strict and loose routes significantly enhances the flexibility of path definitions.

An advantage of using RSVP to establish LSP tunnels is that it enables the allocation of resources along the path. For example, bandwidth can be allocated to an LSP tunnel using standard RSVP reservations and Integrated Services service classes [4].

While resource reservations are useful, they are not mandatory. Indeed, an LSP can be instantiated without any resource reservations whatsoever. Such LSPs without resource reservations can be used, for example, to carry best effort traffic. They can also be used in many other contexts, including implementation of fall-back and recovery policies under fault conditions, and so forth.

1.2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC2119 [6].

The reader is assumed to be familiar with the terminology in [1], [2] and [3].

Abstract Node

A group of nodes whose internal topology is opaque to the ingress node of the LSP. An abstract node is said to be simple if it contains only one physical node.

Explicitly Routed LSP

An LSP whose path is established by a means other than normal IP routing.

Label Switched Path

The path created by the concatenation of one or more label switched hops, allowing a packet to be forwarded by swapping labels from an MPLS node to another MPLS node. For a more precise definition see [2].

LSP

A Label Switched Path

LSP Tunnel

An LSP which is used to tunnel below normal IP routing and/or filtering mechanisms.

Traffic Engineered Tunnel (TE Tunnel)

A set of one or more LSP Tunnels which carries a traffic trunk.

Traffic Trunk

A set of flows aggregated by their service class and then placed on an LSP or set of LSPs called a traffic engineered tunnel. For further discussion see [3].

2. Overview

2.1. LSP Tunnels and Traffic Engineered Tunnels

According to [1], "RSVP defines a 'session' to be a data flow with a particular destination and transport-layer protocol." However, when RSVP and MPLS are combined, a flow or session can be defined with greater flexibility and generality. The ingress node of an LSP can use a variety of means to determine which packets are assigned a particular label. Once a label is assigned to a set of packets, the label effectively defines the "flow" through the LSP. We refer to such an LSP as an "LSP tunnel" because the traffic through it is opaque to intermediate nodes along the label switched path.

New RSVP SESSION, SENDER_TEMPLATE, and FILTER_SPEC objects, called LSP_TUNNEL_IPv4 and LSP_TUNNEL_IPv6 have been defined to support the LSP tunnel feature. The semantics of these objects, from the perspective of a node along the label switched path, is that traffic belonging to the LSP tunnel is identified solely on the basis of packets arriving from the PHOP or "previous hop" (see [1]) with the particular label value(s) assigned by this node to upstream senders to the session. In fact, the IPv4(v6) that appears in the object name only denotes that the destination address is an IPv4(v6) address. When we refer to these objects generically, we use the qualifier LSP_TUNNEL.

In some applications it is useful to associate sets of LSP tunnels. This can be useful during reroute operations or to spread a traffic trunk over multiple paths. In the traffic engineering application such sets are called traffic engineered tunnels (TE tunnels). To enable the identification and association of such LSP tunnels, two identifiers are carried. A tunnel ID is part of the SESSION object. The SESSION object uniquely defines a traffic engineered tunnel. The

SENDER_TEMPLATE and FILTER_SPEC objects carry an LSP ID. The SENDER_TEMPLATE (or FILTER_SPEC) object together with the SESSION object uniquely identifies an LSP tunnel

2.2. Operation of LSP Tunnels

This section summarizes some of the features supported by RSVP as extended by this document related to the operation of LSP tunnels. These include: (1) the capability to establish LSP tunnels with or without QoS requirements, (2) the capability to dynamically reroute an established LSP tunnel, (3) the capability to observe the actual route traversed by an established LSP tunnel, (4) the capability to identify and diagnose LSP tunnels, (5) the capability to preempt an established LSP tunnel under administrative policy control, and (6) the capability to perform downstream-on-demand label allocation, distribution, and binding. In the following paragraphs, these features are briefly described. More detailed descriptions can be found in subsequent sections of this document.

To create an LSP tunnel, the first MPLS node on the path -- that is, the sender node with respect to the path -- creates an RSVP Path message with a session type of LSP_TUNNEL_IPv4 or LSP_TUNNEL_IPv6 and inserts a LABEL_REQUEST object into the Path message. The LABEL_REQUEST object indicates that a label binding for this path is requested and also provides an indication of the network layer protocol that is to be carried over this path. The reason for this is that the network layer protocol sent down an LSP cannot be assumed to be IP and cannot be deduced from the L2 header, which simply identifies the higher layer protocol as MPLS.

If the sender node has knowledge of a route that has high likelihood of meeting the tunnel’s QoS requirements, or that makes efficient use of network resources, or that satisfies some policy criteria, the node can decide to use the route for some or all of its sessions. To do this, the sender node adds an EXPLICIT_ROUTE object to the RSVP Path message. The EXPLICIT_ROUTE object specifies the route as a sequence of abstract nodes.

If, after a session has been successfully established, the sender node discovers a better route, the sender can dynamically reroute the session by simply changing the EXPLICIT_ROUTE object. If problems are encountered with an EXPLICIT_ROUTE object, either because it causes a routing loop or because some intermediate routers do not support it, the sender node is notified.

By adding a RECORD_ROUTE object to the Path message, the sender node can receive information about the actual route that the LSP tunnel traverses. The sender node can also use this object to request

notification from the network concerning changes to the routing path. The RECORD_ROUTE object is analogous to a path vector, and hence can be used for loop detection.

Finally, a SESSION_ATTRIBUTE object can be added to Path messages to aid in session identification and diagnostics. Additional control information, such as setup and hold priorities, resource affinities (see [3]), and local-protection, are also included in this object.

Routers along the path may use the setup and hold priorities along with SENDER_TSPEC and any POLICY_DATA objects contained in Path messages as input to policy control. For instance, in the traffic engineering application, it is very useful to use the Path message as a means of verifying that bandwidth exists at a particular priority along an entire path before preempting any lower priority reservations. If a Path message is allowed to progress when there are insufficient resources, then there is a danger that lower priority reservations downstream of this point will unnecessarily be preempted in a futile attempt to service this request.

When the EXPLICIT_ROUTE object (ERO) is present, the Path message is forwarded towards its destination along a path specified by the ERO. Each node along the path records the ERO in its path state block. Nodes may also modify the ERO before forwarding the Path message. In this case the modified ERO SHOULD be stored in the path state block in addition to the received ERO.

The LABEL_REQUEST object requests intermediate routers and receiver nodes to provide a label binding for the session. If a node is incapable of providing a label binding, it sends a PathErr message with an "unknown object class" error. If the LABEL_REQUEST object is not supported end to end, the sender node will be notified by the first node which does not provide this support.

The destination node of a label-switched path responds to a LABEL_REQUEST by including a LABEL object in its response RSVP Resv message. The LABEL object is inserted in the filter spec list immediately following the filter spec to which it pertains.

The Resv message is sent back upstream towards the sender, following the path state created by the Path message, in reverse order. Note that if the path state was created by use of an ERO, then the Resv message will follow the reverse path of the ERO.

Each node that receives a Resv message containing a LABEL object uses that label for outgoing traffic associated with this LSP tunnel. If the node is not the sender, it allocates a new label and places that label in the corresponding LABEL object of the Resv message which it

sends upstream to the PHOP. The label sent upstream in the LABEL object is the label which this node will use to identify incoming traffic associated with this LSP tunnel. This label also serves as shorthand for the Filter Spec. The node can now update its "Incoming Label Map" (ILM), which is used to map incoming labeled packets to a "Next Hop Label Forwarding Entry" (NHLFE), see [2].

When the Resv message propagates upstream to the sender node, a label-switched path is effectively established.

2.3. Service Classes

This document does not restrict the type of Integrated Service requests for reservations. However, an implementation SHOULD support the Controlled-Load service [4] and the Null Service [16].

2.4. Reservation Styles

The receiver node can select from among a set of possible reservation styles for each session, and each RSVP session must have a particular style. Senders have no influence on the choice of reservation style. The receiver can choose different reservation styles for different LSPs.

An RSVP session can result in one or more LSPs, depending on the reservation style chosen.

Some reservation styles, such as FF, dedicate a particular reservation to an individual sender node. Other reservation styles, such as WF and SE, can share a reservation among several sender nodes. The following sections discuss the different reservation styles and their advantages and disadvantages. A more detailed discussion of reservation styles can be found in [1].

2.4.1. Fixed Filter (FF) Style

The Fixed Filter (FF) reservation style creates a distinct reservation for traffic from each sender that is not shared by other senders. This style is common for applications in which traffic from each sender is likely to be concurrent and independent. The total amount of reserved bandwidth on a link for sessions using FF is the sum of the reservations for the individual senders.

Because each sender has its own reservation, a unique label is assigned to each sender. This can result in a point-to-point LSP between every sender/receiver pair.

2.4.2. Wildcard Filter (WF) Style

With the Wildcard Filter (WF) reservation style, a single shared reservation is used for all senders to a session. The total reservation on a link remains the same regardless of the number of senders.

A single multipoint-to-point label-switched-path is created for all senders to the session. On links that senders to the session share, a single label value is allocated to the session. If there is only one sender, the LSP looks like a normal point-to-point connection. When multiple senders are present, a multipoint-to-point LSP (a reversed tree) is created.

This style is useful for applications in which not all senders send traffic at the same time. A phone conference, for example, is an application where not all speakers talk at the same time. If, however, all senders send simultaneously, then there is no means of getting the proper reservations made. Either the reserved bandwidth on links close to the destination will be less than what is required or then the reserved bandwidth on links close to some senders will be greater than what is required. This restricts the applicability of WF for traffic engineering purposes.

Furthermore, because of the merging rules of WF, EXPLICIT_ROUTE objects cannot be used with WF reservations. As a result of this issue and the lack of applicability to traffic engineering, use of WF is not considered in this document.

2.4.3. Shared Explicit (SE) Style

The Shared Explicit (SE) style allows a receiver to explicitly specify the senders to be included in a reservation. There is a single reservation on a link for all the senders listed. Because each sender is explicitly listed in the Resv message, different labels may be assigned to different senders, thereby creating separate LSPs.

SE style reservations can be provided using multipoint-to-point label-switched-path or LSP per sender. Multipoint-to-point LSPs may be used when path messages do not carry the EXPLICIT_ROUTE object, or when Path messages have identical EXPLICIT_ROUTE objects. In either of these cases a common label may be assigned.

Path messages from different senders can each carry their own ERO, and the paths taken by the senders can converge and diverge at any point in the network topology. When Path messages have differing EXPLICIT_ROUTE objects, separate LSPs for each EXPLICIT_ROUTE object must be established.

2.5. Rerouting Traffic Engineered Tunnels

One of the requirements for Traffic Engineering is the capability to reroute an established TE tunnel under a number of conditions, based on administrative policy. For example, in some contexts, an administrative policy may dictate that a given TE tunnel is to be rerouted when a more "optimal" route becomes available. Another important context when TE tunnel reroute is usually required is upon failure of a resource along the TE tunnel's established path. Under some policies, it may also be necessary to return the TE tunnel to its original path when the failed resource becomes re-activated.

In general, it is highly desirable not to disrupt traffic, or adversely impact network operations while TE tunnel rerouting is in progress. This adaptive and smooth rerouting requirement necessitates establishing a new LSP tunnel and transferring traffic from the old LSP tunnel onto it before tearing down the old LSP tunnel. This concept is called "make-before-break." A problem can arise because the old and new LSP tunnels might compete with each other for resources on network segments which they have in common. Depending on availability of resources, this competition can cause Admission Control to prevent the new LSP tunnel from being established. An advantage of using RSVP to establish LSP tunnels is that it solves this problem very elegantly.

To support make-before-break in a smooth fashion, it is necessary that on links that are common to the old and new LSPs, resources used by the old LSP tunnel should not be released before traffic is transitioned to the new LSP tunnel, and reservations should not be counted twice because this might cause Admission Control to reject the new LSP tunnel.

A similar situation can arise when one wants to increase the bandwidth of a TE tunnel. The new reservation will be for the full amount needed, but the actual allocation needed is only the delta between the new and old bandwidth. If policy is being applied to PATH messages by intermediate nodes, then a PATH message requesting too much bandwidth will be rejected. In this situation simply increasing the bandwidth request without changing the SENDER_TEMPLATE, could result in a tunnel being torn down, depending upon local policy.

The combination of the LSP_TUNNEL SESSION object and the SE reservation style naturally accommodates smooth transitions in bandwidth and routing. The idea is that the old and new LSP tunnels share resources along links which they have in common. The LSP_TUNNEL SESSION object is used to narrow the scope of the RSVP session to the particular TE tunnel in question. To uniquely identify a TE tunnel, we use the combination of the destination IP address (an address of the node which is the egress of the tunnel), a Tunnel ID, and the tunnel ingress node's IP address, which is placed in the Extended Tunnel ID field.

During the reroute or bandwidth-increase operation, the tunnel ingress needs to appear as two different senders to the RSVP session. This is achieved by the inclusion of the "LSP ID", which is carried in the SENDER_TEMPLATE and FILTER_SPEC objects. Since the semantics of these objects are changed, a new C-Types are assigned.

To effect a reroute, the ingress node picks a new LSP ID and forms a new SENDER_TEMPLATE. The ingress node then creates a new ERO to define the new path. Thereafter the node sends a new Path Message using the original SESSION object and the new SENDER_TEMPLATE and ERO. It continues to use the old LSP and refresh the old Path message. On links that are not held in common, the new Path message is treated as a conventional new LSP tunnel setup. On links held in common, the shared SESSION object and SE style allow the LSP to be established sharing resources with the old LSP. Once the ingress node receives a Resv message for the new LSP, it can transition traffic to it and tear down the old LSP.

To effect a bandwidth-increase, a new Path Message with a new LSP_ID can be used to attempt a larger bandwidth reservation while the current LSP_ID continues to be refreshed to ensure that the reservation is not lost if the larger reservation fails.

2.6. Path MTU

Standard RSVP [1] and Int-Serv [11] provide the RSVP sender with the minimum MTU available between the sender and the receiver. This path MTU identification capability is also provided for LSPs established via RSVP.

Path MTU information is carried, depending on which is present, in the Integrated Services or Null Service objects. When using Integrated Services objects, path MTU is provided based on the procedures defined in [11]. Path MTU identification when using Null Service objects is defined in [16].

With standard RSVP, the path MTU information is used by the sender to check which IP packets exceed the path MTU. For packets that exceed the path MTU, the sender either fragments the packets or, when the IP datagram has the "Don't Fragment" bit set, issues an ICMP destination unreachable message. This path MTU related handling is also required for LSPs established via RSVP.

The following algorithm applies to all unlabeled IP datagrams and to any labeled packets which the node knows to be IP datagrams, to which labels need to be added before forwarding. For labeled packets the bottom of stack is found, the IP header examined.

Using the terminology defined in [5], an LSR MUST execute the following algorithm:

1. Let N be the number of bytes in the label stack (i.e, 4 times the number of label stack entries) including labels to be added by this node.

2. Let M be the smaller of the "Maximum Initially Labeled IP Datagram Size" or of (Path MTU - N).

When the size of an IPv4 datagram (without labels) exceeds the value of M,

If the DF bit is not set in the IPv4 header, then

(a) the datagram MUST be broken into fragments, each of whose size is no greater than M, and

(b) each fragment MUST be labeled and then forwarded.

If the DF bit is set in the IPv4 header, then

(a) the datagram MUST NOT be forwarded

(b) Create an ICMP Destination Unreachable Message:

i. set its Code field [12] to "Fragmentation Required and DF Set",
ii. set its Next-Hop MTU field [13] to M

(c) If possible, transmit the ICMP Destination Unreachable Message to the source of the of the discarded datagram.

When the size of an IPv6 datagram (without labels) exceeds the value of M,

(a) the datagram MUST NOT be forwarded

(b) Create an ICMP Packet too Big Message with the Next-Hop link MTU field [14] set to M

(c) If possible, transmit the ICMP Packet too Big Message to the source of the of the discarded datagram.

3. LSP Tunnel related Message Formats

Five new objects are defined in this section:

Object name	Applicable RSVP messages
LABEL_REQUEST	Path
LABEL	Resv
EXPLICIT_ROUTE	Path
RECORD_ROUTE	Path, Resv
SESSION_ATTRIBUTE	Path

New C-Types are also assigned for the SESSION, SENDER_TEMPLATE, and FILTER_SPEC, objects.

Detailed descriptions of the new objects are given in later sections. All new objects are OPTIONAL with respect to RSVP. An implementation can choose to support a subset of objects. However, the LABEL_REQUEST and LABEL objects are mandatory with respect to this specification.

The LABEL and RECORD_ROUTE objects, are sender specific. In Resv messages they MUST appear after the associated FILTER_SPEC and prior to any subsequent FILTER_SPEC.

The relative placement of EXPLICIT_ROUTE, LABEL_REQUEST, and SESSION_ATTRIBUTE objects is simply a recommendation. The ordering of these objects is not important, so an implementation MUST be prepared to accept objects in any order.

3.1. Path Message

The format of the Path message is as follows:

```
<Path Message> ::=      <Common Header> [ <INTEGRITY> ]
                        <SESSION> <RSVP_HOP>
                        <TIME_VALUES>
                        [ <EXPLICIT_ROUTE> ]
                        <LABEL_REQUEST>
                        [ <SESSION_ATTRIBUTE> ]
```

```
                              [ <POLICY_DATA> ... ]
                              <sender descriptor>

      <sender descriptor> ::=  <SENDER_TEMPLATE> <SENDER_TSPEC>
                              [ <ADSPEC> ]
                              [ <RECORD_ROUTE> ]
```

3.2. Resv Message

The format of the Resv message is as follows:

```
      <Resv Message> ::=       <Common Header> [ <INTEGRITY> ]
                              <SESSION>  <RSVP_HOP>
                              <TIME_VALUES>
                              [ <RESV_CONFIRM> ]  [ <SCOPE> ]
                              [ <POLICY_DATA> ... ]
                              <STYLE> <flow descriptor list>

      <flow descriptor list> ::= <FF flow descriptor list>
                              | <SE flow descriptor>


      <FF flow descriptor list> ::= <FLOWSPEC> <FILTER_SPEC>
                              <LABEL> [ <RECORD_ROUTE> ]
                              | <FF flow descriptor list>
                              <FF flow descriptor>

      <FF flow descriptor> ::= [ <FLOWSPEC> ] <FILTER_SPEC> <LABEL>
                              [ <RECORD_ROUTE> ]

      <SE flow descriptor> ::= <FLOWSPEC> <SE filter spec list>

      <SE filter spec list> ::= <SE filter spec>
                              | <SE filter spec list> <SE filter spec>

      <SE filter spec> ::=     <FILTER_SPEC> <LABEL> [ <RECORD_ROUTE> ]
```

Note: LABEL and RECORD_ROUTE (if present), are bound to the preceding FILTER_SPEC. No more than one LABEL and/or RECORD_ROUTE may follow each FILTER_SPEC.

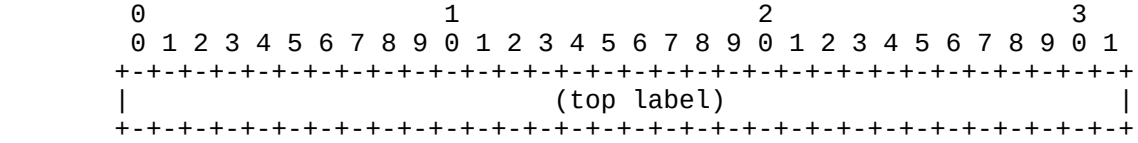
4. LSP Tunnel related Objects

4.1. Label Object

Labels MAY be carried in Resv messages. For the FF and SE styles, a label is associated with each sender. The label for a sender MUST immediately follow the FILTER_SPEC for that sender in the Resv message.

The LABEL object has the following format:

LABEL class = 16, C_Type = 1



The contents of a LABEL is a single label, encoded in 4 octets. Each generic MPLS label is an unsigned integer in the range 0 through 1048575. Generic MPLS labels and FR labels are encoded right aligned in 4 octets. ATM labels are encoded with the VPI right justified in bits 0-15 and the VCI right justified in bits 16-31.

4.1.1. Handling Label Objects in Resv messages

In MPLS a node may support multiple label spaces, perhaps associating a unique space with each incoming interface. For the purposes of the following discussion, the term "same label" means the identical label value drawn from the identical label space. Further, the following applies only to unicast sessions.

Labels received in Resv messages on different interfaces are always considered to be different even if the label value is the same.

4.1.1.1. Downstream

The downstream node selects a label to represent the flow. If a label range has been specified in the label request, the label MUST be drawn from that range. If no label is available the node sends a PathErr message with an error code of "routing problem" and an error value of "label allocation failure".

If a node receives a Resv message that has assigned the same label value to multiple senders, then that node MAY also assign a single value to those same senders or to any subset of those senders. Note

that if a node intends to police individual senders to a session, it MUST assign unique labels to those senders.

In the case of ATM, one further condition applies. Some ATM nodes are not capable of merging streams. These nodes MAY indicate this by setting a bit in the label request to zero. The M-bit in the LABEL_REQUEST object of C-Type 2, label request with ATM label range, serves this purpose. The M-bit SHOULD be set by nodes which are merge capable. If for any senders the M-bit is not set, the downstream node MUST assign unique labels to those senders.

Once a label is allocated, the node formats a new LABEL object. The node then sends the new LABEL object as part of the Resv message to the previous hop. The node SHOULD be prepared to forward packets carrying the assigned label prior to sending the Resv message. The LABEL object SHOULD be kept in the Reservation State Block. It is then used in the next Resv refresh event for formatting the Resv message.

A node is expected to send a Resv message before its refresh timers expire if the contents of the LABEL object change.

4.1.1.2. Upstream

A node uses the label carried in the LABEL object as the outgoing label associated with the sender. The router allocates a new label and binds it to the incoming interface of this session/sender. This is the same interface that the router uses to forward Resv messages to the previous hops.

Several circumstance can lead to an unacceptable label.

1. the node is a merge incapable ATM switch but the downstream node has assigned the same label to two senders

2. The implicit null label was assigned, but the node is not capable of doing a penultimate pop for the associated L3PID

3. The assigned label is outside the requested label range

In any of these events the node send a ResvErr message with an error code of "routing problem" and an error value of "unacceptable label value".

4.1.2. Non-support of the Label Object

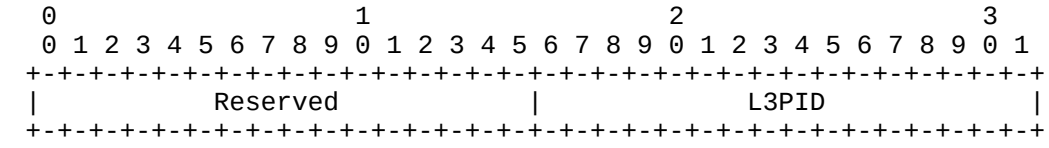
Under normal circumstances, a node should never receive a LABEL object in a Resv message unless it had included a LABEL_REQUEST object in the corresponding Path message. However, an RSVP router that does not recognize the LABEL object sends a ResvErr with the error code "Unknown object class" toward the receiver. This causes the reservation to fail.

4.2. Label Request Object

The Label Request Class is 19. Currently there are three possible C_Types. Type 1 is a Label Request without label range. Type 2 is a label request with an ATM label range. Type 3 is a label request with a Frame Relay label range. The LABEL_REQUEST object formats are shown below.

4.2.1. Label Request without Label Range

Class = 19, C_Type = 1



Reserved

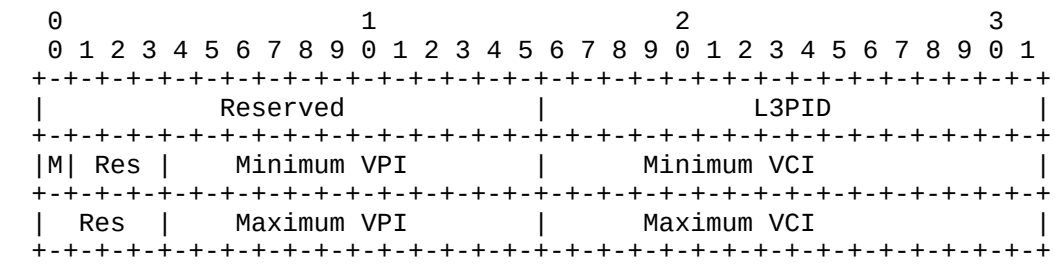
This field is reserved. It MUST be set to zero on transmission and MUST be ignored on receipt.

L3PID

an identifier of the layer 3 protocol using this path. Standard Ethertype values are used.

4.2.2. Label Request with ATM Label Range

Class = 19, C_Type = 2



Reserved (Res)

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

L3PID

an identifier of the layer 3 protocol using this path. Standard Ethertype values are used.

M

Setting this bit to one indicates that the node is capable of merging in the data plane

Minimum VPI (12 bits)

This 12 bit field specifies the lower bound of a block of Virtual Path Identifiers that is supported on the originating switch. If the VPI is less than 12-bits it MUST be right justified in this field and preceding bits MUST be set to zero.

Minimum VCI (16 bits)

This 16 bit field specifies the lower bound of a block of Virtual Connection Identifiers that is supported on the originating switch. If the VCI is less than 16-bits it MUST be right justified in this field and preceding bits MUST be set to zero.

Maximum VPI (12 bits)

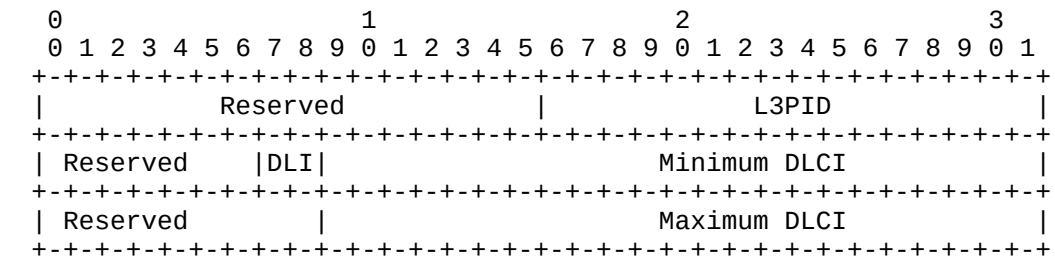
This 12 bit field specifies the upper bound of a block of Virtual Path Identifiers that is supported on the originating switch. If the VPI is less than 12-bits it MUST be right justified in this field and preceding bits MUST be set to zero.

Maximum VCI (16 bits)

This 16 bit field specifies the upper bound of a block of Virtual Connection Identifiers that is supported on the originating switch. If the VCI is less than 16-bits it MUST be right justified in this field and preceding bits MUST be set to zero.

4.2.3. Label Request with Frame Relay Label Range

Class = 19, C_Type = 3



Reserved

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

L3PID

an identifier of the layer 3 protocol using this path. Standard Ethertype values are used.

DLI

DLCI Length Indicator. The number of bits in the DLCI. The following values are supported:

Len	DLCI bits
0	10
2	23

Minimum DLCI

This 23-bit field specifies the lower bound of a block of Data Link Connection Identifiers (DLCIs) that is supported on the originating switch. The DLCI MUST be right justified in this field and unused bits MUST be set to 0.

Maximum DLCI

This 23-bit field specifies the upper bound of a block of Data Link Connection Identifiers (DLCIs) that is supported on the originating switch. The DLCI MUST be right justified in this field and unused bits MUST be set to 0.

4.2.4. Handling of LABEL_REQUEST

To establish an LSP tunnel the sender creates a Path message with a LABEL_REQUEST object. The LABEL_REQUEST object indicates that a label binding for this path is requested and provides an indication of the network layer protocol that is to be carried over this path. This permits non-IP network layer protocols to be sent down an LSP. This information can also be useful in actual label allocation, because some reserved labels are protocol specific, see [5].

The LABEL_REQUEST SHOULD be stored in the Path State Block, so that Path refresh messages will also contain the LABEL_REQUEST object. When the Path message reaches the receiver, the presence of the LABEL_REQUEST object triggers the receiver to allocate a label and to place the label in the LABEL object for the corresponding Resv message. If a label range was specified, the label MUST be allocated from that range. A receiver that accepts a LABEL_REQUEST object MUST include a LABEL object in Resv messages pertaining to that Path message. If a LABEL_REQUEST object was not present in the Path message, a node MUST NOT include a LABEL object in a Resv message for that Path message's session and PHOP.

A node that sends a LABEL_REQUEST object MUST be ready to accept and correctly process a LABEL object in the corresponding Resv messages.

A node that recognizes a LABEL_REQUEST object, but that is unable to support it (possibly because of a failure to allocate labels) SHOULD send a PathErr with the error code "Routing problem" and the error value "MPLS label allocation failure." This includes the case where a label range has been specified and a label cannot be allocated from that range.

A node which receives and forwards a Path message each with a LABEL_REQUEST object, MUST copy the L3PID from the received LABEL_REQUEST object to the forwarded LABEL_REQUEST object.

If the receiver cannot support the protocol L3PID, it SHOULD send a PathErr with the error code "Routing problem" and the error value "Unsupported L3PID." This causes the RSVP session to fail.

4.2.5. Non-support of the Label Request Object

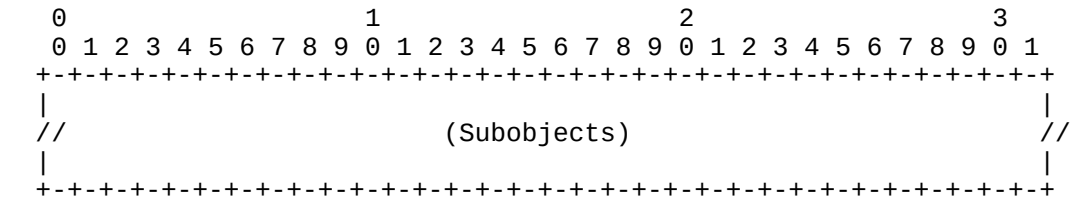
An RSVP router that does not recognize the LABEL_REQUEST object sends a PathErr with the error code "Unknown object class" toward the sender. An RSVP router that recognizes the LABEL_REQUEST object but does not recognize the C_Type sends a PathErr with the error code "Unknown object C_Type" toward the sender. This causes the path setup to fail. The sender should notify management that a LSP cannot be established and possibly take action to continue the reservation without the LABEL_REQUEST.

RSVP is designed to cope gracefully with non-RSVP routers anywhere between senders and receivers. However, obviously, non-RSVP routers cannot convey labels via RSVP. This means that if a router has a neighbor that is known to not be RSVP capable, the router MUST NOT advertise the LABEL_REQUEST object when sending messages that pass through the non-RSVP routers. The router SHOULD send a PathErr back to the sender, with the error code "Routing problem" and the error value "MPLS being negotiated, but a non-RSVP capable router stands in the path." This same message SHOULD be sent, if a router receives a LABEL_REQUEST object in a message from a non-RSVP capable router. See [1] for a description of how a downstream router can determine the presence of non-RSVP routers.

4.3. Explicit Route Object

Explicit routes are specified via the EXPLICIT_ROUTE object (ERO). The Explicit Route Class is 20. Currently one C_Type is defined, Type 1 Explicit Route. The EXPLICIT_ROUTE object has the following format:

Class = 20, C_Type = 1



Subobjects

The contents of an EXPLICIT_ROUTE object are a series of variable-length data items called subobjects. The subobjects are defined in section 4.3.3 below.

If a Path message contains multiple EXPLICIT_ROUTE objects, only the first object is meaningful. Subsequent EXPLICIT_ROUTE objects MAY be ignored and SHOULD NOT be propagated.

4.3.1. Applicability

The EXPLICIT_ROUTE object is intended to be used only for unicast situations. Applications of explicit routing to multicast are a topic for further research.

The EXPLICIT_ROUTE object is to be used only when all routers along the explicit route support RSVP and the EXPLICIT_ROUTE object. The EXPLICIT_ROUTE object is assigned a class value of the form 0bbbbbbb. RSVP routers that do not support the object will therefore respond with an "Unknown Object Class" error.

4.3.2. Semantics of the Explicit Route Object

An explicit route is a particular path in the network topology. Typically, the explicit route is determined by a node, with the intent of directing traffic along that path.

An explicit route is described as a list of groups of nodes along the explicit route. In addition to the ability to identify specific nodes along the path, an explicit route can identify a group of nodes that must be traversed along the path. This capability allows the routing system a significant amount of local flexibility in fulfilling a request for an explicit route. This capability allows the generator of the explicit route to have imperfect information about the details of the path.

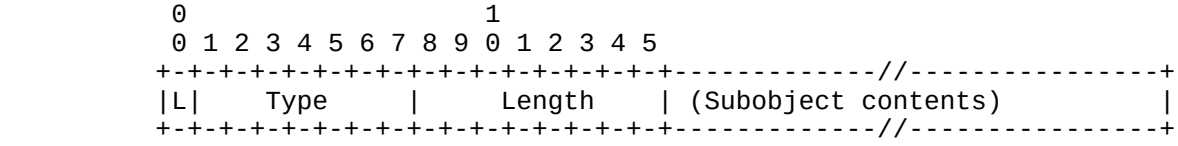
The explicit route is encoded as a series of subobjects contained in an EXPLICIT_ROUTE object. Each subobject identifies a group of nodes in the explicit route. An explicit route is thus a specification of groups of nodes to be traversed.

To formalize the discussion, we call each group of nodes an abstract node. Thus, we say that an explicit route is a specification of a set of abstract nodes to be traversed. If an abstract node consists of only one node, we refer to it as a simple abstract node.

As an example of the concept of abstract nodes, consider an explicit route that consists solely of Autonomous System number subobjects. Each subobject corresponds to an Autonomous System in the global topology. In this case, each Autonomous System is an abstract node, and the explicit route is a path that includes each of the specified Autonomous Systems. There may be multiple hops within each Autonomous System, but these are opaque to the source node for the explicit route.

4.3.3. Subobjects

The contents of an EXPLICIT_ROUTE object are a series of variable-length data items called subobjects. Each subobject has the form:



L

The L bit is an attribute of the subobject. The L bit is set if the subobject represents a loose hop in the explicit route. If the bit is not set, the subobject represents a strict hop in the explicit route.

Type

The Type indicates the type of contents of the subobject. Currently defined values are:

1	IPv4 prefix
2	IPv6 prefix
32	Autonomous system number

Length

The Length contains the total length of the subobject in bytes, including the L, Type and Length fields. The Length MUST be at least 4, and MUST be a multiple of 4.

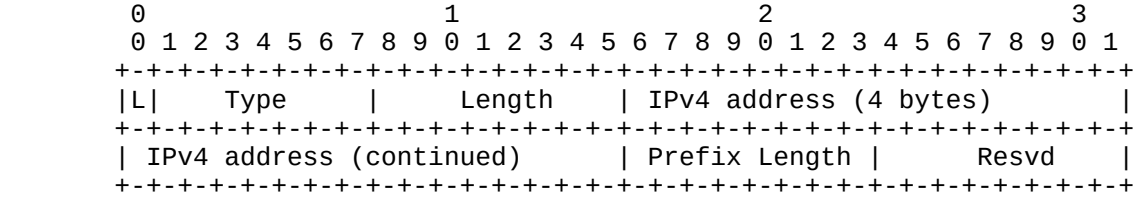
4.3.3.1. Strict and Loose Subobjects

The L bit in the subobject is a one-bit attribute. If the L bit is set, then the value of the attribute is 'loose.' Otherwise, the value of the attribute is 'strict.' For brevity, we say that if the value of the subobject attribute is 'loose' then it is a 'loose subobject.' Otherwise, it's a 'strict subobject.' Further, we say that the abstract node of a strict or loose subobject is a strict or a loose node, respectively. Loose and strict nodes are always interpreted relative to their prior abstract nodes.

The path between a strict node and its preceding node MUST include only network nodes from the strict node and its preceding abstract node.

The path between a loose node and its preceding node MAY include other network nodes that are not part of the strict node or its preceding abstract node.

4.3.3.2. Subobject 1: IPv4 prefix



L

The L bit is an attribute of the subobject. The L bit is set if the subobject represents a loose hop in the explicit route. If the bit is not set, the subobject represents a strict hop in the explicit route.

Type

0x01 IPv4 address

Length

The Length contains the total length of the subobject in bytes, including the Type and Length fields. The Length is always 8.

IPv4 address

An IPv4 address. This address is treated as a prefix based on the prefix length value below. Bits beyond the prefix are ignored on receipt and SHOULD be set to zero on transmission.

Prefix length

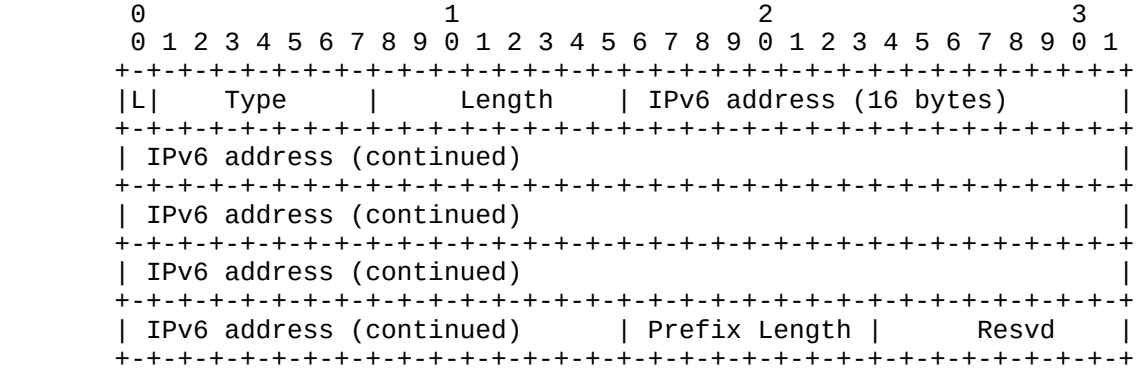
Length in bits of the IPv4 prefix

Padding

Zero on transmission. Ignored on receipt.

The contents of an IPv4 prefix subobject are a 4-octet IPv4 address, a 1-octet prefix length, and a 1-octet pad. The abstract node represented by this subobject is the set of nodes that have an IP address which lies within this prefix. Note that a prefix length of 32 indicates a single IPv4 node.

4.3.3.3. Subobject 2: IPv6 Prefix



L

The L bit is an attribute of the subobject. The L bit is set if the subobject represents a loose hop in the explicit route. If the bit is not set, the subobject represents a strict hop in the explicit route.

Type

0x02 IPv6 address

Length

The Length contains the total length of the subobject in bytes, including the Type and Length fields. The Length is always 20.

IPv6 address

An IPv6 address. This address is treated as a prefix based on the prefix length value below. Bits beyond the prefix are ignored on receipt and SHOULD be set to zero on transmission.

Prefix Length

Length in bits of the IPv6 prefix.

Padding

Zero on transmission. Ignored on receipt.

The contents of an IPv6 prefix subobject are a 16-octet IPv6 address, a 1-octet prefix length, and a 1-octet pad. The abstract node represented by this subobject is the set of nodes that have an IP address which lies within this prefix. Note that a prefix length of 128 indicates a single IPv6 node.

4.3.3.4. Subobject 32: Autonomous System Number

The contents of an Autonomous System (AS) number subobject are a 2-octet AS number. The abstract node represented by this subobject is the set of nodes belonging to the autonomous system.

The length of the AS number subobject is 4 octets.

4.3.4. Processing of the Explicit Route Object

4.3.4.1. Selection of the Next Hop

A node receiving a Path message containing an EXPLICIT_ROUTE object must determine the next hop for this path. This is necessary because the next abstract node along the explicit route might be an IP subnet or an Autonomous System. Therefore, selection of this next hop may involve a decision from a set of feasible alternatives. The criteria used to make a selection from feasible alternatives is implementation dependent and can also be impacted by local policy, and is beyond the

scope of this specification. However, it is assumed that each node will make a best effort attempt to determine a loop-free path. Note that paths so determined can be overridden by local policy.

To determine the next hop for the path, a node performs the following steps:

1) The node receiving the RSVP message MUST first evaluate the first subobject. If the node is not part of the abstract node described by the first subobject, it has received the message in error and SHOULD return a "Bad initial subobject" error. If there is no first subobject, the message is also in error and the system SHOULD return a "Bad EXPLICIT_ROUTE object" error.

2) If there is no second subobject, this indicates the end of the explicit route. The EXPLICIT_ROUTE object SHOULD be removed from the Path message. This node may or may not be the end of the path. Processing continues with section 4.3.4.2, where a new EXPLICIT_ROUTE object MAY be added to the Path message.

3) Next, the node evaluates the second subobject. If the node is also a part of the abstract node described by the second subobject, then the node deletes the first subobject and continues processing with step 2, above. Note that this makes the second subobject into the first subobject of the next iteration and allows the node to identify the next abstract node on the path of the message after possible repeated application(s) of steps 2 and 3.

4) Abstract Node Border Case: The node determines whether it is topologically adjacent to the abstract node described by the second subobject. If so, the node selects a particular next hop which is a member of the abstract node. The node then deletes the first subobject and continues processing with section 4.3.4.2.

5) Interior of the Abstract Node Case: Otherwise, the node selects a next hop within the abstract node of the first subobject (which the node belongs to) that is along the path to the abstract node of the second subobject (which is the next abstract node). If no such path exists then there are two cases:

5a) If the second subobject is a strict subobject, there is an error and the node SHOULD return a "Bad strict node" error.

5b) Otherwise, if the second subobject is a loose subobject, the node selects any next hop that is along the path to the next abstract node. If no path exists, there is an error, and the node SHOULD return a "Bad loose node" error.

6) Finally, the node replaces the first subobject with any subobject that denotes an abstract node containing the next hop. This is necessary so that when the explicit route is received by the next hop, it will be accepted.

4.3.4.2. Adding subobjects to the Explicit Route Object

After selecting a next hop, the node MAY alter the explicit route in the following ways.

If, as part of executing the algorithm in section 4.3.4.1, the

EXPLICIT_ROUTE object is removed, the node MAY add a new EXPLICIT_ROUTE object.

Otherwise, if the node is a member of the abstract node for the first subobject, a series of subobjects MAY be inserted before the first subobject or MAY replace the first subobject. Each subobject in this series MUST denote an abstract node that is a subset of the current abstract node.

Alternately, if the first subobject is a loose subobject, an arbitrary series of subobjects MAY be inserted prior to the first subobject.

4.3.5. Loops

While the EXPLICIT_ROUTE object is of finite length, the existence of loose nodes implies that it is possible to construct forwarding loops during transients in the underlying routing protocol. This can be detected by the originator of the explicit route through the use of another opaque route object called the RECORD_ROUTE object. The RECORD_ROUTE object is used to collect detailed path information and is useful for loop detection and for diagnostics.

4.3.6. Forward Compatibility

It is anticipated that new subobjects may be defined over time. A node which encounters an unrecognized subobject during its normal ERO processing sends a PathErr with the error code "Routing Error" and error value of "Bad Explicit Route Object" toward the sender. The EXPLICIT_ROUTE object is included, truncated (on the left) to the offending subobject. The presence of an unrecognized subobject which is not encountered in a node’s ERO processing SHOULD be ignored. It is passed forward along with the rest of the remaining ERO stack.

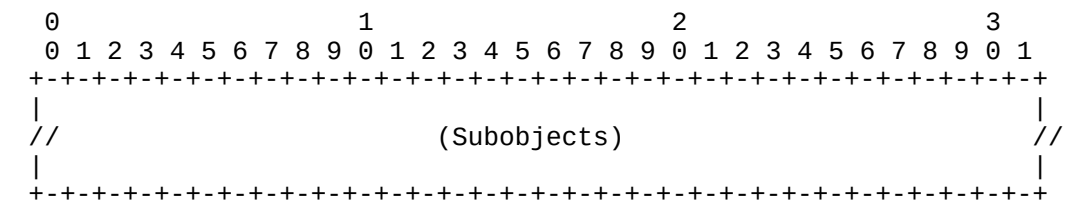
4.3.7. Non-support of the Explicit Route Object

An RSVP router that does not recognize the EXPLICIT_ROUTE object sends a PathErr with the error code "Unknown object class" toward the sender. This causes the path setup to fail. The sender should notify management that a LSP cannot be established and possibly take action to continue the reservation without the EXPLICIT_ROUTE or via a different explicit route.

4.4. Record Route Object

Routes can be recorded via the RECORD_ROUTE object (RRO). Optionally, labels may also be recorded. The Record Route Class is 21. Currently one C_Type is defined, Type 1 Record Route. The RECORD_ROUTE object has the following format:

Class = 21, C_Type = 1



Subobjects

The contents of a RECORD_ROUTE object are a series of variable-length data items called subobjects. The subobjects are defined in section 4.4.1 below.

The RRO can be present in both RSVP Path and Resv messages. If a Path message contains multiple RROs, only the first RRO is meaningful. Subsequent RROs SHOULD be ignored and SHOULD NOT be propagated. Similarly, if in a Resv message multiple RROs are encountered following a FILTER_SPEC before another FILTER_SPEC is encountered, only the first RRO is meaningful. Subsequent RROs SHOULD be ignored and SHOULD NOT be propagated.

4.4.1. Subobjects

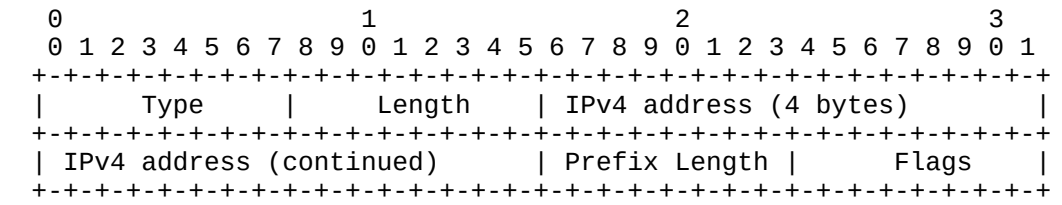
The contents of a RECORD_ROUTE object are a series of variable-length data items called subobjects. Each subobject has its own Length field. The length contains the total length of the subobject in bytes, including the Type and Length fields. The length MUST always be a multiple of 4, and at least 4.

Subobjects are organized as a last-in-first-out stack. The first subobject relative to the beginning of RRO is considered the top. The last subobject is considered the bottom. When a new subobject is added, it is always added to the top.

An empty RRO with no subobjects is considered illegal.

Three kinds of subobjects are currently defined.

4.4.1.1. Subobject 1: IPv4 address



Type

0x01 IPv4 address

Length

The Length contains the total length of the subobject in bytes, including the Type and Length fields. The Length is always 8.

IPv4 address

A 32-bit unicast, host address. Any network-reachable interface address is allowed here. Illegal addresses, such as certain loopback addresses, SHOULD NOT be used.

Prefix length

32

Flags

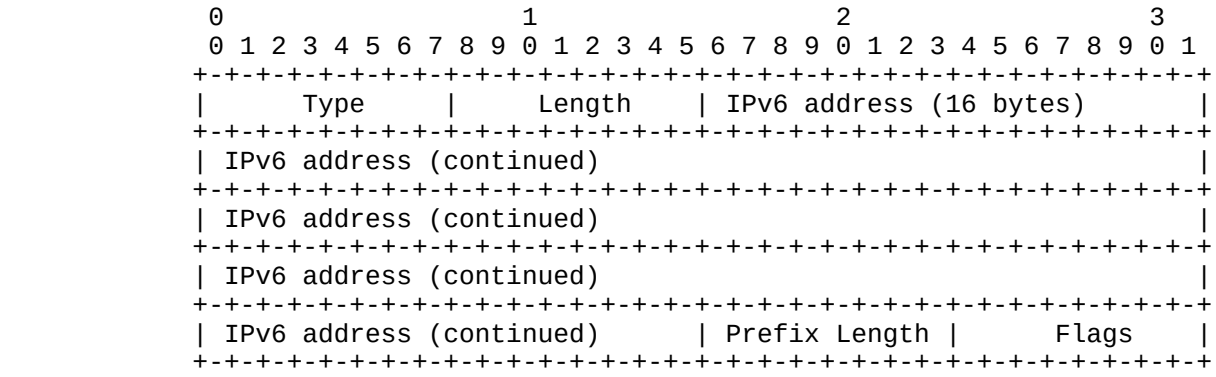
0x01 Local protection available

Indicates that the link downstream of this node is protected via a local repair mechanism. This flag can only be set if the Local protection flag was set in the SESSION_ATTRIBUTE object of the corresponding Path message.

0x02 Local protection in use

Indicates that a local repair mechanism is in use to maintain this tunnel (usually in the face of an outage of the link it was previously routed over).

4.4.1.2. Subobject 2: IPv6 address



Type

0x02 IPv6 address

Length

The Length contains the total length of the subobject in bytes, including the Type and Length fields. The Length is always 20.

IPv6 address

A 128-bit unicast host address.

Prefix length

128

Flags

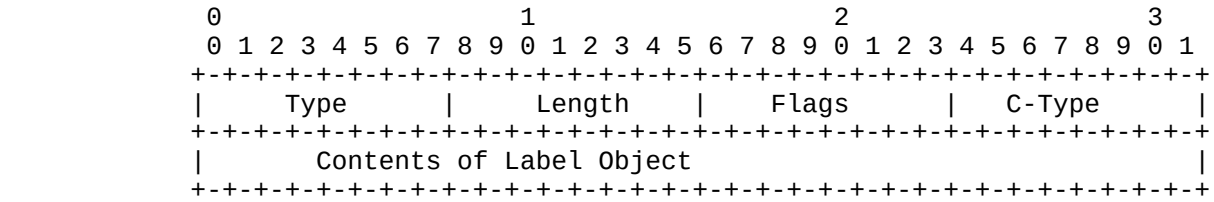
0x01 Local protection available

Indicates that the link downstream of this node is protected via a local repair mechanism. This flag can only be set if the Local protection flag was set in the SESSION_ATTRIBUTE object of the corresponding Path message.

0x02 Local protection in use

Indicates that a local repair mechanism is in use to maintain this tunnel (usually in the face of an outage of the link it was previously routed over).

4.4.1.3. Subobject 3, Label



Type

0x03 Label

Length

The Length contains the total length of the subobject in bytes, including the Type and Length fields.

Flags

0x01 = Global label
This flag indicates that the label will be understood if received on any interface.

C-Type

The C-Type of the included Label Object. Copied from the Label Object.

Contents of Label Object

The contents of the Label Object. Copied from the Label Object

4.4.2. Applicability

Only the procedures for use in unicast sessions are defined here.

There are three possible uses of RRO in RSVP. First, an RRO can function as a loop detection mechanism to discover L3 routing loops, or loops inherent in the explicit route. The exact procedure for doing so is described later in this document.

Second, an RRO collects up-to-date detailed path information hop-by-hop about RSVP sessions, providing valuable information to the sender or receiver. Any path change (due to network topology changes) will be reported.

Third, RRO syntax is designed so that, with minor changes, the whole object can be used as input to the EXPLICIT_ROUTE object. This is useful if the sender receives RRO from the receiver in a Resv message, applies it to EXPLICIT_ROUTE object in the next Path message in order to "pin down session path".

4.4.3. Processing RRO

Typically, a node initiates an RSVP session by adding the RRO to the Path message. The initial RRO contains only one subobject - the sender's IP addresses. If the node also desires label recording, it sets the Label_Recording flag in the SESSION_ATTRIBUTE object.

When a Path message containing an RRO is received by an intermediate router, the router stores a copy of it in the Path State Block. The RRO is then used in the next Path refresh event for formatting Path messages. When a new Path message is to be sent, the router adds a new subobject to the RRO and appends the resulting RRO to the Path message before transmission.

The newly added subobject MUST be this router's IP address. The address to be added SHOULD be the interface address of the outgoing Path messages. If there are multiple addresses to choose from, the decision is a local matter. However, it is RECOMMENDED that the same address be chosen consistently.

When the Label_Recording flag is set in the SESSION_ATTRIBUTE object, nodes doing route recording SHOULD include a Label Record subobject. If the node is using a global label space, then it SHOULD set the Global Label flag.

The Label Record subobject is pushed onto the RECORD_ROUTE object prior to pushing on the node's IP address. A node MUST NOT push on a Label Record subobject without also pushing on an IPv4 or IPv6 subobject.

Note that on receipt of the initial Path message, a node is unlikely to have a label to include. Once a label is obtained, the node SHOULD include the label in the RRO in the next Path refresh event.

If the newly added subobject causes the RRO to be too big to fit in a Path (or Resv) message, the RRO object SHALL be dropped from the message and message processing continues as normal. A PathErr (or

ResvErr) message SHOULD be sent back to the sender (or receiver). An error code of "Notify" and an error value of "RRO too large for MTU" is used. If the receiver receives such a ResvErr, it SHOULD send a PathErr message with error code of "Notify" and an error value of "RRO notification".

A sender receiving either of these error values SHOULD remove the RRO from the Path message.

Nodes SHOULD resend the above PathErr or ResvErr message each n seconds where n is the greater of 15 and the refresh interval for the associated Path or RESV message. The node MAY apply limits and/or back-off timers to limit the number of messages sent.

An RSVP router can decide to send Path messages before its refresh time if the RRO in the next Path message is different from the previous one. This can happen if the contents of the RRO received from the previous hop router changes or if this RRO is newly added to (or deleted from) the Path message.

When the destination node of an RSVP session receives a Path message with an RRO, this indicates that the sender node needs route recording. The destination node initiates the RRO process by adding an RRO to Resv messages. The processing mirrors that of the Path messages. The only difference is that the RRO in a Resv message records the path information in the reverse direction.

Note that each node along the path will now have the complete route from source to destination. The Path RRO will have the route from the source to this node; the Resv RRO will have the route from this node to the destination. This is useful for network management.

A received Path message without an RRO indicates that the sender node no longer needs route recording. Subsequent Resv messages SHALL NOT contain an RRO.

4.4.4. Loop Detection

As part of processing an incoming RRO, an intermediate router looks into all subobjects contained within the RRO. If the router determines that it is already in the list, a forwarding loop exists.

An RSVP session is loop-free if downstream nodes receive Path messages or upstream nodes receive Resv messages with no routing loops detected in the contained RRO.

There are two broad classifications of forwarding loops. The first class is the transient loop, which occurs as a normal part of operations as L3 routing tries to converge on a consistent forwarding path for all destinations. The second class of forwarding loop is the permanent loop, which normally results from network mis-configuration.

The action performed by a node on receipt of an RRO depends on the message type in which the RRO is received.

For Path messages containing a forwarding loop, the router builds and sends a "Routing problem" PathErr message, with the error value "loop detected," and drops the Path message. Until the loop is eliminated, this session is not suitable for forwarding data packets. How the loop eliminated is beyond the scope of this document.

For Resv messages containing a forwarding loop, the router simply drops the message. Resv messages should not loop if Path messages do not loop.

4.4.5. Forward Compatibility

New subobjects may be defined for the RRO. When processing an RRO, unrecognized subobjects SHOULD be ignored and passed on. When processing an RRO for loop detection, a node SHOULD parse over any unrecognized objects. Loop detection works by detecting subobjects which were inserted by the node itself on an earlier pass of the object. This ensures that the subobjects necessary for loop detection are always understood.

4.4.6. Non-support of RRO

The RRO object is to be used only when all routers along the path support RSVP and the RRO object. The RRO object is assigned a class value of the form 0bbbbbbb. RSVP routers that do not support the object will therefore respond with an "Unknown Object Class" error.

4.5. Error Codes for ERO and RRO

In the processing described above, certain errors must be reported as either a "Routing Problem" or "Notify". The value of the "Routing Problem" error code is 24; the value of the "Notify" error code is 25.

The following defines error values for the Routing Problem Error Code:

Value	Error:
1	Bad EXPLICIT_ROUTE object
2	Bad strict node
3	Bad loose node
4	Bad initial subobject
5	No route available toward destination
6	Unacceptable label value
7	RRO indicated routing loops
8	MPLS being negotiated, but a non-RSVP-capable router stands in the path
9	MPLS label allocation failure
10	Unsupported L3PID

For the Notify Error Code, the 16 bits of the Error Value field are:

ss00 cccc cccc cccc

The high order bits are as defined under Error Code 1. (See [1]).

When ss = 00, the following subcodes are defined:

1	RRO too large for MTU
2	RRO notification
3	Tunnel locally repaired

4.6. Session, Sender Template, and Filter Spec Objects

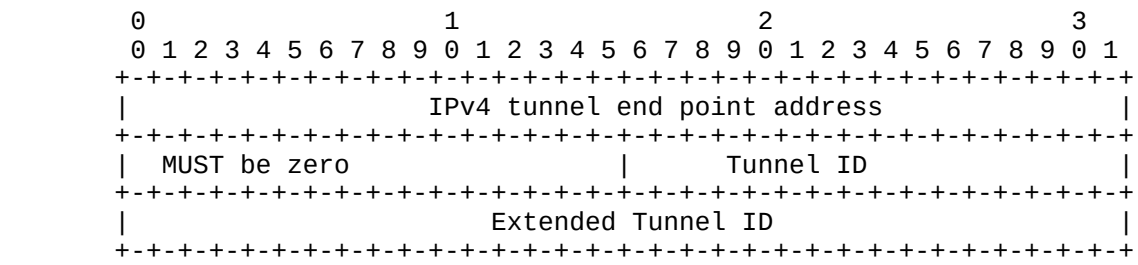
New C-Types are defined for the SESSION, SENDER_TEMPLATE and FILTER_SPEC objects.

The LSP_TUNNEL objects have the following format:

4.6.1. Session Object

4.6.1.1. LSP_TUNNEL_IPv4 Session Object

Class = SESSION, LSP_TUNNEL_IPv4 C-Type = 7



IPv4 tunnel end point address

IPv4 address of the egress node for the tunnel.

Tunnel ID

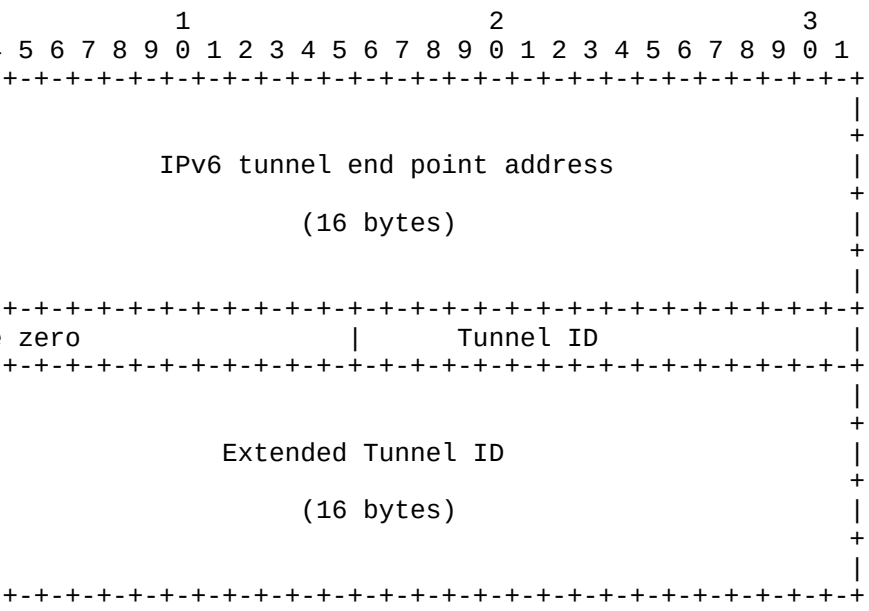
A 16-bit identifier used in the SESSION that remains constant over the life of the tunnel.

Extended Tunnel ID

A 32-bit identifier used in the SESSION that remains constant over the life of the tunnel. Normally set to all zeros. Ingress nodes that wish to narrow the scope of a SESSION to the ingress-egress pair may place their IPv4 address here as a globally unique identifier.

4.6.1.2. LSP_TUNNEL_IPv6 Session Object

Class = SESSION, LSP_TUNNEL_IPv6 C_Type = 8



IPv6 tunnel end point address

IPv6 address of the egress node for the tunnel.

Tunnel ID

A 16-bit identifier used in the SESSION that remains constant over the life of the tunnel.

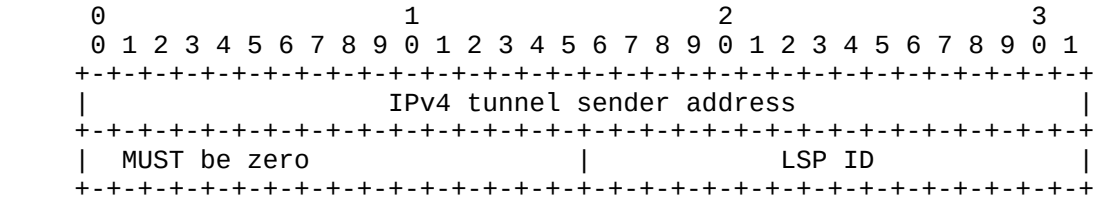
Extended Tunnel ID

A 16-byte identifier used in the SESSION that remains constant over the life of the tunnel. Normally set to all zeros. Ingress nodes that wish to narrow the scope of a SESSION to the ingress-egress pair may place their IPv6 address here as a globally unique identifier.

4.6.2. Sender Template Object

4.6.2.1. LSP_TUNNEL_IPv4 Sender Template Object

Class = SENDER_TEMPLATE, LSP_TUNNEL_IPv4 C-Type = 7



IPv4 tunnel sender address

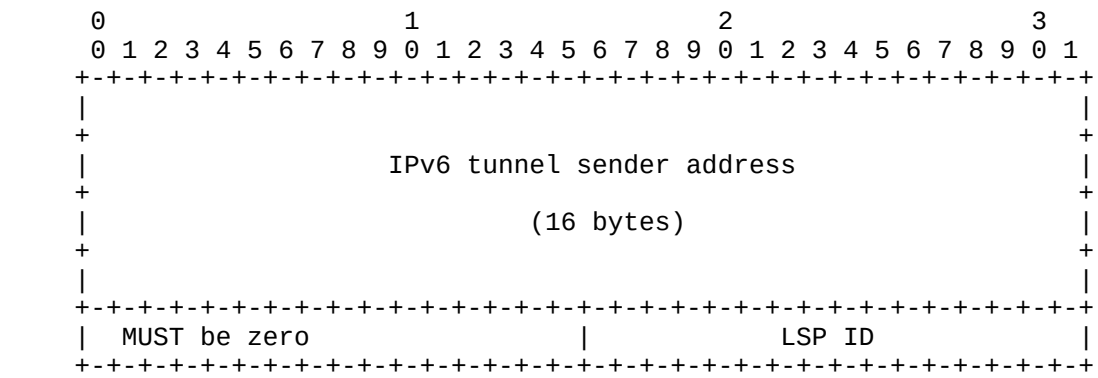
IPv4 address for a sender node

LSP ID

A 16-bit identifier used in the SENDER_TEMPLATE and the FILTER_SPEC that can be changed to allow a sender to share resources with itself.

4.6.2.2. LSP_TUNNEL_IPv6 Sender Template Object

Class = SENDER_TEMPLATE, LSP_TUNNEL_IPv6 C_Type = 8



IPv6 tunnel sender address

IPv6 address for a sender node

LSP ID

A 16-bit identifier used in the SENDER_TEMPLATE and the FILTER_SPEC that can be changed to allow a sender to share resources with itself.

4.6.3. Filter Specification Object

4.6.3.1. LSP_TUNNEL_IPv4 Filter Specification Object

Class = FILTER SPECIFICATION, LSP_TUNNEL_IPv4 C-Type = 7

The format of the LSP_TUNNEL_IPv4 FILTER_SPEC object is identical to the LSP_TUNNEL_IPv4 SENDER_TEMPLATE object.

4.6.3.2. LSP_TUNNEL_IPv6 Filter Specification Object

Class = FILTER SPECIFICATION, LSP_TUNNEL_IPv6 C_Type = 8

The format of the LSP_TUNNEL_IPv6 FILTER_SPEC object is identical to the LSP_TUNNEL_IPv6 SENDER_TEMPLATE object.

4.6.4. Reroute and Bandwidth Increase Procedure

This section describes how to setup a tunnel that is capable of maintaining resource reservations (without double counting) while it is being rerouted or while it is attempting to increase its bandwidth. In the initial Path message, the ingress node forms a SESSION object, assigns a Tunnel_ID, and places its IPv4 address in the Extended_Tunnel_ID. It also forms a SENDER_TEMPLATE and assigns a LSP_ID. Tunnel setup then proceeds according to the normal procedure.

On receipt of the Path message, the egress node sends a Resv message with the STYLE Shared Explicit toward the ingress node.

When an ingress node with an established path wants to change that path, it forms a new Path message as follows. The existing SESSION object is used. In particular the Tunnel_ID and Extended_Tunnel_ID are unchanged. The ingress node picks a new LSP_ID to form a new SENDER_TEMPLATE. It creates an EXPLICIT_ROUTE object for the new route. The new Path message is sent. The ingress node refreshes both the old and new path messages.

The egress node responds with a Resv message with an SE flow descriptor formatted as:

<FLOWSPEC><old_FILTER_SPEC><old_LABEL_OBJECT><new_FILTER_SPEC>
<new_LABEL_OBJECT>

(Note that if the PHOPs are different, then two messages are sent each with the appropriate FILTER_SPEC and LABEL_OBJECT.)

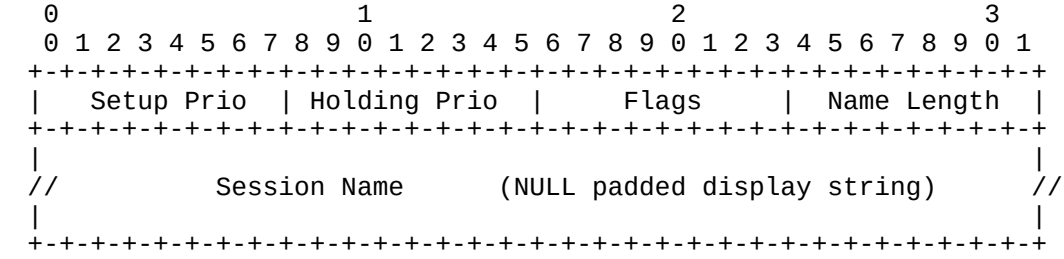
When the ingress node receives the Resv Message(s), it may begin using the new route. It SHOULD send a PathTear message for the old route.

4.7. Session Attribute Object

The Session Attribute Class is 207. Two C_Types are defined, LSP_TUNNEL, C-Type = 7 and LSP_TUNNEL_RA, C-Type = 1. The LSP_TUNNEL_RA C-Type includes all the same fields as the LSP_TUNNEL C-Type. Additionally it carries resource affinity information. The formats are as follows:

4.7.1. Format without resource affinities

SESSION_ATTRIBUTE class = 207, LSP_TUNNEL C-Type = 7



Setup Priority

The priority of the session with respect to taking resources, in the range of 0 to 7. The value 0 is the highest priority. The Setup Priority is used in deciding whether this session can preempt another session.

Holding Priority

The priority of the session with respect to holding resources, in the range of 0 to 7. The value 0 is the highest priority. Holding Priority is used in deciding whether this session can be preempted by another session.

Flags

0x01 Local protection desired

This flag permits transit routers to use a local repair mechanism which may result in violation of the explicit route object. When a fault is detected on an adjacent downstream link or node, a transit router can reroute traffic for fast service restoration.

0x02 Label recording desired

This flag indicates that label information should be included when doing a route record.

0x04 SE Style desired

This flag indicates that the tunnel ingress node may choose to reroute this tunnel without tearing it down. A tunnel egress node SHOULD use the SE Style when responding with a Resv message.

Name Length

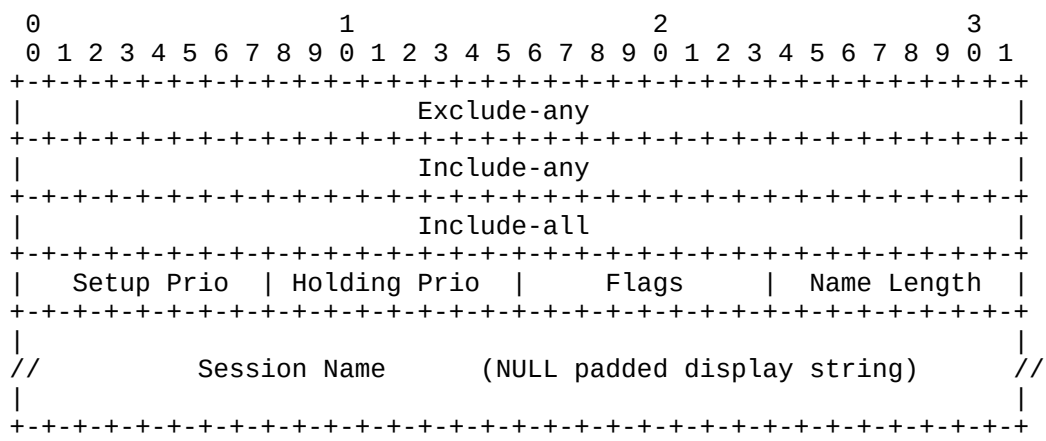
The length of the display string before padding, in bytes.

Session Name

A null padded string of characters.

4.7.2. Format with resource affinities

SESSION_ATTRIBUTE class = 207, LSP_TUNNEL_RA C-Type = 1



Exclude-any

A 32-bit vector representing a set of attribute filters associated with a tunnel any of which renders a link unacceptable.

Include-any

A 32-bit vector representing a set of attribute filters associated with a tunnel any of which renders a link acceptable (with respect to this test). A null set (all bits set to zero) automatically passes.

Include-all

A 32-bit vector representing a set of attribute filters associated with a tunnel all of which must be present for a link to be acceptable (with respect to this test). A null set (all bits set to zero) automatically passes.

Setup Priority

The priority of the session with respect to taking resources, in the range of 0 to 7. The value 0 is the highest priority. The Setup Priority is used in deciding whether this session can preempt another session.

Holding Priority

The priority of the session with respect to holding resources, in the range of 0 to 7. The value 0 is the highest priority. Holding Priority is used in deciding whether this session can be preempted by another session.

Flags

0x01 Local protection desired

This flag permits transit routers to use a local repair mechanism which may result in violation of the explicit route object. When a fault is detected on an adjacent downstream link or node, a transit router can reroute traffic for fast service restoration.

0x02 Label recording desired

This flag indicates that label information should be included when doing a route record.

0x04 SE Style desired

This flag indicates that the tunnel ingress node may choose to reroute this tunnel without tearing it down. A tunnel egress node SHOULD use the SE Style when responding with a Resv message.

Name Length

The length of the display string before padding, in bytes.

Session Name

A null padded string of characters.

4.7.3. Procedures applying to both C-Types

The support of setup and holding priorities is OPTIONAL. A node can recognize this information but be unable to perform the requested operation. The node SHOULD pass the information downstream unchanged.

As noted above, preemption is implemented by two priorities. The Setup Priority is the priority for taking resources. The Holding Priority is the priority for holding a resource. Specifically, the

Holding Priority is the priority at which resources assigned to this session will be reserved. The Setup Priority SHOULD never be higher than the Holding Priority for a given session.

The setup and holding priorities are directly analogous to the preemption and defending priorities as defined in [9]. While the interaction of these two objects is ultimately a matter of policy, the following default interaction is RECOMMENDED.

When both objects are present, the preemption priority policy element is used. A mapping between the priority spaces is defined as follows. A session attribute priority S is mapped to a preemption priority P by the formula P = 2^(14-2S). The reverse mapping is shown in the following table.

Preemption Priority	Session Attribute Priority
0 - 3	7
4 - 15	6
16 - 63	5
64 - 255	4
256 - 1023	3
1024 - 4095	2
4096 - 16383	1
16384 - 65535	0

When a new Path message is considered for admission, the bandwidth requested is compared with the bandwidth available at the priority specified in the Setup Priority.

If the requested bandwidth is not available a PathErr message is returned with an Error Code of 01, Admission Control Failure, and an Error Value of 0x0002. The first 0 in the Error Value indicates a globally defined subcode and is not informational. The 002 indicates "requested bandwidth unavailable".

If the requested bandwidth is less than the unused bandwidth then processing is complete. If the requested bandwidth is available, but is in use by lower priority sessions, then lower priority sessions (beginning with the lowest priority) MAY be preempted to free the necessary bandwidth.

When preemption is supported, each preempted reservation triggers a TC_Preempt() upcall to local clients, passing a subcode that indicates the reason. A ResvErr and/or PathErr with the code "Policy Control failure" SHOULD be sent toward the downstream receivers and upstream senders.

The support of local-protection is OPTIONAL. A node may recognize the local-protection Flag but may be unable to perform the requested operation. In this case, the node SHOULD pass the information downstream unchanged.

The recording of the Label subobject in the ROUTE_RECORD object is controlled by the label-recording-desired flag in the SESSION_ATTRIBUTE object. Since the Label subobject is not needed for all applications, it is not automatically recorded. The flag allows applications to request this only when needed.

The contents of the Session Name field are a string, typically of display-able characters. The Length MUST always be a multiple of 4 and MUST be at least 8. For an object length that is not a multiple of 4, the object is padded with trailing NULL characters. The Name Length field contains the actual string length.

4.7.4. Resource Affinity Procedures

Resource classes and resource class affinities are described in [3]. In this document we use the briefer term resource affinities for the latter term. Resource classes can be associated with links and advertised in routing protocols. Resource class affinities are used by RSVP in two ways. In order to be validated a link MUST pass the three tests below. If the test fails a PathErr with the code "policy control failure" SHOULD be sent.

When a new reservation is considered for admission over a strict node in an ERO, a node MAY validate the resource affinities with the resource classes of that link. When a node is choosing links in order to extend a loose node of an ERO, the node MUST validate the resource classes of those links against the resource affinities. If no acceptable links can be found to extend the ERO, the node SHOULD send a PathErr message with an error code of "Routing Problem" and an error value of "no route available toward destination".

In order to be validated a link MUST pass the following three tests.

To precisely describe the tests use the definitions in the object description above. We also define

Link-attr A 32-bit vector representing attributes associated with a link.

The three tests are

1. Exclude-any

   This test excludes a link from consideration if the link carries any of the attributes in the set.

   (link-attr & exclude-any) == 0

2. Include-any

   This test accepts a link if the link carries any of the attributes in the set.

   (include-any == 0) | ((link-attr & include-any) != 0)

3. Include-all

   This test accepts a link only if the link carries all of the attributes in the set.

   (include-all == 0) | (((link-attr & include-all) ^ include-all) == 0)

For a link to be acceptable, all three tests MUST pass. If the test fails, the node SHOULD send a PathErr message with an error code of "Routing Problem" and an error value of "no route available toward destination".

If a Path message contains multiple SESSION_ATTRIBUTE objects, only the first SESSION_ATTRIBUTE object is meaningful. Subsequent SESSION_ATTRIBUTE objects can be ignored and need not be forwarded.

All RSVP routers, whether they support the SESSION_ATTRIBUTE object or not, SHALL forward the object unmodified. The presence of non-RSVP routers anywhere between senders and receivers has no impact on this object.

5. Hello Extension

The RSVP Hello extension enables RSVP nodes to detect when a neighboring node is not reachable. The mechanism provides node to node failure detection. When such a failure is detected it is handled much the same as a link layer communication failure. This mechanism is intended to be used when notification of link layer failures is not available and unnumbered links are not used, or when the failure detection mechanisms provided by the link layer are not sufficient for timely node failure detection.

It should be noted that node failure detection is not the same as a link failure detection mechanism, particularly in the case of multiple parallel unnumbered links.

The Hello extension is specifically designed so that one side can use the mechanism while the other side does not. Neighbor failure detection may be initiated at any time. This includes when neighbors first learn about each other, or just when neighbors are sharing Resv or Path state.

The Hello extension is composed of a Hello message, a HELLO REQUEST object and a HELLO ACK object. Hello processing between two neighbors supports independent selection of, typically configured, failure detection intervals. Each neighbor can autonomously issue HELLO REQUEST objects. Each request is answered by an acknowledgment. Hello Messages also contain enough information so that one neighbor can suppress issuing hello requests and still perform neighbor failure detection. A Hello message may be included as a sub-message within a bundle message.

Neighbor failure detection is accomplished by collecting and storing a neighbor's "instance" value. If a change in value is seen or if the neighbor is not properly reporting the locally advertised value, then the neighbor is presumed to have reset. When a neighbor's value is seen to change or when communication is lost with a neighbor, then the instance value advertised to that neighbor is also changed. The HELLO objects provide a mechanism for polling for and providing an instance value. A poll request also includes the sender's instance value. This allows the receiver of a poll to optionally treat the poll as an implicit poll response. This optional handling is an optimization that can reduce the total number of polls and responses processed by a pair of neighbors. In all cases, when both sides support the optimization the result will be only one set of polls and responses per failure detection interval. Depending on selected intervals, the same benefit can occur even when only one neighbor supports the optimization.

5.1. Hello Message Format

Hello Messages are always sent between two RSVP neighbors. The IP source address is the IP address of the sending node. The IP destination address is the IP address of the neighbor node.

The HELLO mechanism is intended for use between immediate neighbors. When HELLO messages are being the exchanged between immediate neighbors, the IP TTL field of all outgoing HELLO messages SHOULD be set to 1.

The Hello message has a Msg Type of 20. The Hello message format is as follows:

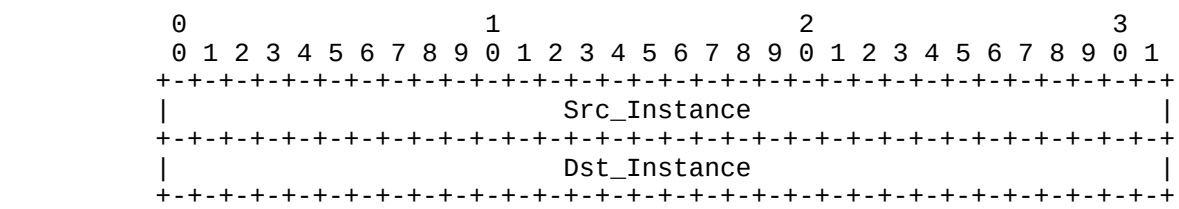
```
<Hello Message> ::= <Common Header> [ <INTEGRITY> ]
                          <HELLO>
```

5.2. HELLO Object formats

The HELLO Class is 22. There are two C_Types defined.

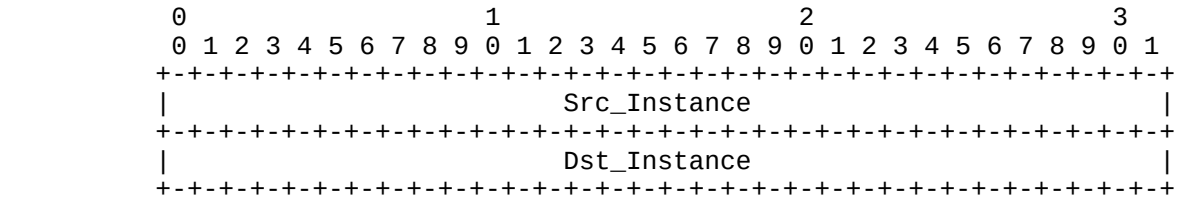
5.2.1. HELLO REQUEST object

Class = HELLO Class, C_Type = 1



5.2.2. HELLO ACK object

Class = HELLO Class, C_Type = 2



Src_Instance: 32 bits

a 32 bit value that represents the sender's instance. The advertiser maintains a per neighbor representation/value. This value MUST change when the sender is reset, when the node reboots, or when communication is lost to the neighboring node and otherwise remains the same. This field MUST NOT be set to zero (0).

Dst_Instance: 32 bits

The most recently received Src_Instance value received from the neighbor. This field MUST be set to zero (0) when no value has ever been seen from the neighbor.

5.3. Hello Message Usage

The Hello Message is completely OPTIONAL. All messages may be ignored by nodes which do not wish to participate in Hello message processing. The balance of this section is written assuming that the receiver as well as the sender is participating. In particular, the use of MUST and SHOULD with respect to the receiver applies only to a node that supports Hello message processing.

A node periodically generates a Hello message containing a HELLO REQUEST object for each neighbor who's status is being tracked. The periodicity is governed by the hello_interval. This value MAY be configured on a per neighbor basis. The default value is 5 ms.

When generating a message containing a HELLO REQUEST object, the sender fills in the Src_Instance field with a value representing it's per neighbor instance. This value MUST NOT change while the agent is exchanging Hellos with the corresponding neighbor. The sender also fills in the Dst_Instance field with the Src_Instance value most recently received from the neighbor. For reference, call this variable Neighbor_Src_Instance. If no value has ever been received from the neighbor or this node considers communication to the neighbor to have been lost, the Neighbor_Src_Instance is set to zero (0). The generation of a message SHOULD be suppressed when a HELLO REQUEST object was received from the destination node within the prior hello_interval interval.

On receipt of a message containing a HELLO REQUEST object, the receiver MUST generate a Hello message containing a HELLO ACK object. The receiver SHOULD also verify that the neighbor has not reset. This is done by comparing the sender's Src_Instance field value with the previously received value. If the Neighbor_Src_Instance value is zero, and the Src_Instance field is non-zero, the Neighbor_Src_Instance is updated with the new value. If the value differs or the Src_Instance field is zero, then the node MUST treat the neighbor as if communication has been lost.

The receiver of a HELLO REQUEST object SHOULD also verify that the neighbor is reflecting back the receiver's Instance value. This is done by comparing the received Dst_Instance field with the Src_Instance field value most recently transmitted to that neighbor. If the neighbor continues to advertise a wrong non-zero value after a configured number of intervals, then the node MUST treat the neighbor as if communication has been lost.

On receipt of a message containing a HELLO ACK object, the receiver MUST verify that the neighbor has not reset. This is done by comparing the sender's Src_Instance field value with the previously

received value. If the Neighbor_Src_Instance value is zero, and the Src_Instance field is non-zero, the Neighbor_Src_Instance is updated with the new value. If the value differs or the Src_Instance field is zero, then the node MUST treat the neighbor as if communication has been lost.

The receiver of a HELLO ACK object MUST also verify that the neighbor is reflecting back the receiver's Instance value. If the neighbor advertises a wrong value in the Dst_Instance field, then a node MUST treat the neighbor as if communication has been lost.

If no Instance values are received, via either REQUEST or ACK objects, from a neighbor within a configured number of hello_intervals, then a node MUST presume that it cannot communicate with the neighbor. The default for this number is 3.5.

When communication is lost or presumed to be lost as described above, a node MAY re-initiate HELLOs. If a node does re-initiate it MUST use a Src_Instance value different than the one advertised in the previous HELLO message. This new value MUST continue to be advertised to the corresponding neighbor until a reset or reboot occurs, or until another communication failure is detected. If a new instance value has not been received from the neighbor, then the node MUST advertise zero in the Dst_instance value field.

5.4. Multi-Link Considerations

As previously noted, the Hello extension is targeted at detecting node failures not per link failures. When there is only one link between neighboring nodes or when all links between a pair of nodes fail, the distinction between node and link failures is not really meaningful and handling of such failures has already been covered. When there are multiple links shared between neighbors, there are special considerations. When the links between neighbors are numbered, then Hellos MUST be run on each link and the previously described mechanisms apply.

When the links are unnumbered, link failure detection MUST be provided by some means other than Hellos. Each node SHOULD use a single Hello exchange with the neighbor. The case where all links have failed, is the same as the no received value case mentioned in the previous section.

5.5. Compatibility

The Hello extension does not affect the processing of any other RSVP message. The only effect is to allow a link (node) down event to be declared sooner than it would have been. RSVP response to that condition is unchanged.

The Hello extension is fully backwards compatible. The Hello class is assigned a class value of the form 0bbbbbbb. Depending on the implementation, implementations that do not support the extension will either silently discard Hello messages or will respond with an "Unknown Object Class" error. In either case the sender will fail to see an acknowledgment for the issued Hello.

6. Security Considerations

In principle these extensions to RSVP pose no security exposures over and above RFC 2205[1]. However, there is a slight change in the trust model. Traffic sent on a normal RSVP session can be filtered according to source and destination addresses as well as port numbers. In this specification, filtering occurs only on the basis of an incoming label. For this reason an administration may wish to limit the domain over which LSP tunnels can be established. This can be accomplished by setting filters on various ports to deny action on a RSVP path message with a SESSION object of type LSP_TUNNEL_IPv4 (7) or LSP_TUNNEL_IPv6 (8).

7. IANA Considerations

IANA assigns values to RSVP protocol parameters. Within the current document an EXPLICIT_ROUTE object and a ROUTE_RECORD object are defined. Each of these objects contain subobjects. This section defines the rules for the assignment of subobject numbers. This section uses the terminology of BCP 26 "Guidelines for Writing an IANA Considerations Section in RFCs" [15].

EXPLICIT_ROUTE Subobject Type

EXPLICIT_ROUTE Subobject Type is a 7-bit number that identifies the function of the subobject. There are no range restrictions. All possible values are available for assignment.

Following the policies outlined in [15], subobject types in the range 0 - 63 (0x00 - 0x3F) are allocated through an IETF Consensus action, codes in the range 64 - 95 (0x40 - 0x5F) are allocated as First Come First Served, and codes in the range 96 - 127 (0x60 - 0x7F) are reserved for Private Use.

ROUTE_RECORD Subobject Type

ROUTE_RECORD Subobject Type is an 8-bit number that identifies the function of the subobject. There are no range restrictions. All possible values are available for assignment.

Following the policies outlined in [15], subobject types in the range 0 - 127 (0x00 - 0x7F) are allocated through an IETF Consensus action, codes in the range 128 - 191 (0x80 - 0xBF) are allocated as First Come First Served, and codes in the range 192 - 255 (0xC0 - 0xFF) are reserved for Private Use.

The following assignments are made in this document.

7.1. Message Types

Message Number	Message Name
20	Hello

7.2. Class Numbers and C-Types

Class Number	Class Name
1	SESSION

Class Types or C-Types:

7	LSP Tunnel IPv4
8	LSP Tunnel IPv6

Class Number	Class Name
10	FILTER_SPEC

Class Types or C-Types:

7	LSP Tunnel IPv4
8	LSP Tunnel IPv6

Class Number	Class Name
11	SENDER_TEMPLATE

Class Types or C-Types:

7	LSP Tunnel IPv4
8	LSP Tunnel IPv6

16 RSVP_LABEL

Class Types or C-Types:

1 Type 1 Label

19 LABEL_REQUEST

Class Types or C-Types:

1 Without Label Range
2 With ATM Label Range
3 With Frame Relay Label Range

20 EXPLICIT_ROUTE

Class Types or C-Types:

1 Type 1 Explicit Route

21 ROUTE_RECORD

Class Types or C-Types:

1 Type 1 Route Record

22 HELLO

Class Types or C-Types:

1 Request
2 Acknowledgment

207 SESSION_ATTRIBUTE

Class Types or C-Types:

1 LSP_TUNNEL_RA
7 LSP Tunnel

7.3. Error Codes and Globally-Defined Error Value Sub-Codes

The following list extends the basic list of Error Codes and Values that are defined in [RFC2205].

Error Code	Meaning
24	Routing Problem

This Error Code has the following globally-defined Error Value sub-codes:

1	Bad EXPLICIT_ROUTE object
2	Bad strict node
3	Bad loose node
4	Bad initial subobject
5	No route available toward destination
6	Unacceptable label value
7	RRO indicated routing loops
8	MPLS being negotiated, but a non-RSVP-capable router stands in the path
9	MPLS label allocation failure
10	Unsupported L3PID

25	Notify Error

This Error Code has the following globally-defined Error Value sub-codes:

1	RRO too large for MTU
2	RRO Notification
3	Tunnel locally repaired

7.4. Subobject Definitions

Subobjects of the EXPLICIT_ROUTE object with C-Type 1:

1	IPv4 prefix
2	IPv6 prefix
32	Autonomous system number

Subobjects of the RECORD_ROUTE object with C-Type 1:

1	IPv4 address
2	IPv6 address
3	Label

8. Intellectual Property Considerations

The IETF has been notified of intellectual property rights claimed in regard to some or all of the specification contained in this document. For more information consult the online list of claimed rights.

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11. Authors' Addresses

Daniel O. Awduche
Movaz Networks, Inc.
7926 Jones Branch Drive, Suite 615
McLean, VA 22102
Voice: +1 703-298-5291
EMail: awduche@movaz.com

Lou Berger
Movaz Networks, Inc.
7926 Jones Branch Drive, Suite 615
McLean, VA 22102
Voice: +1 703 847 1801
EMail: lberger@movaz.com

Der-Hwa Gan
Juniper Networks, Inc.
385 Ravendale Drive
Mountain View, CA 94043
EMail: dhg@juniper.net

Tony Li
Procket Networks
3910 Freedom Circle, Ste. 102A
Santa Clara CA 95054
EMail: tli@procket.com

Vijay Srinivasan
Cosine Communications, Inc.
1200 Bridge Parkway
Redwood City, CA 94065
Voice: +1 650 628 4892
EMail: vsriniva@cosinecom.com

George Swallow
Cisco Systems, Inc.
250 Apollo Drive
Chelmsford, MA 01824
Voice: +1 978 244 8143
EMail: swallow@cisco.com

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