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Aggarwal et al.

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(54) **MPLS TRAFFIC ENGINEERING FOR POINT-TO-MULTIPOINT LABEL SWITCHED PATHS**

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H04L 12/28 (2006.01)

(52) **U.S. Cl.** **370/390**; 370/395.2

(58) **Field of Classification Search** 370/389, 370/395.21, 400, 256, 390, 395.2
See application file for complete search history.

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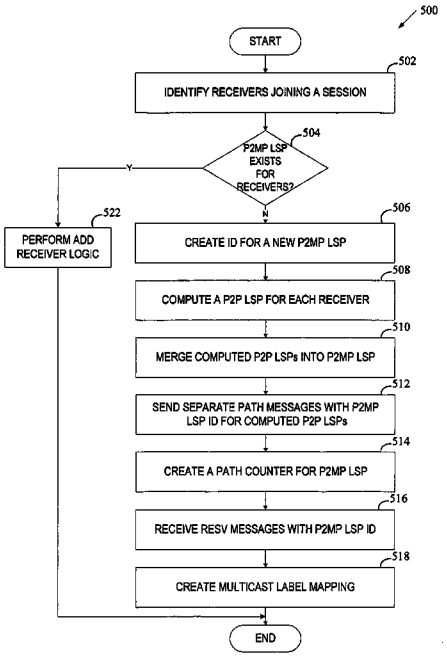
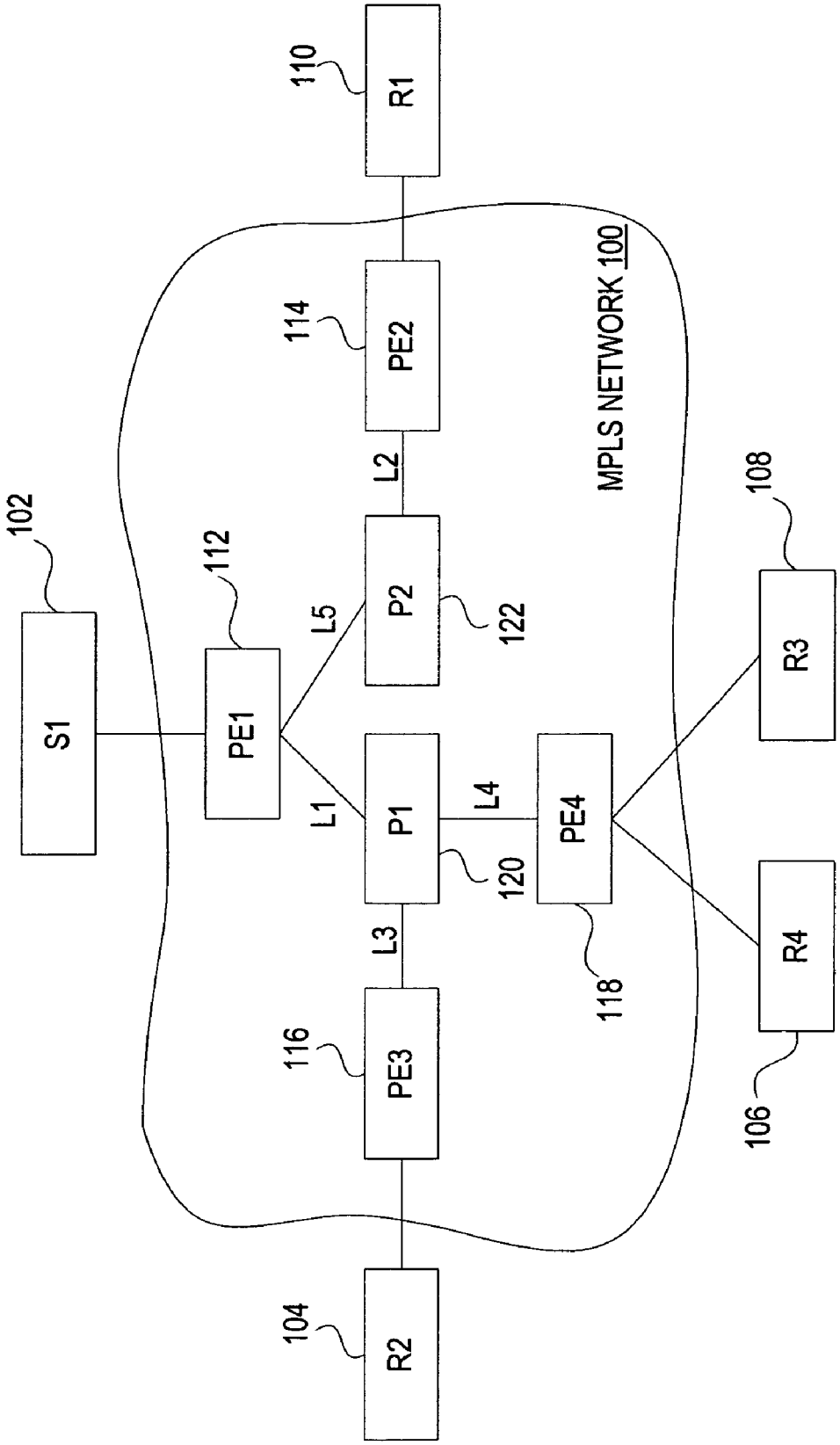
(57) **ABSTRACT**

A method and apparatus for providing point-to-multipoint label switch paths (LSPs) in a Multi-Protocol Label Switching (MPLS) network is described. In one embodiment, a point-to-multipoint LSP is built in a MPLS network by using Resource Reservation Protocol Traffic Engineering (RSVP-TE) to signal the point-to-multipoint LSP as separate point-to-point LSPs and to merge the separate point-to-point LSPs into the point-to-multipoint LSP.

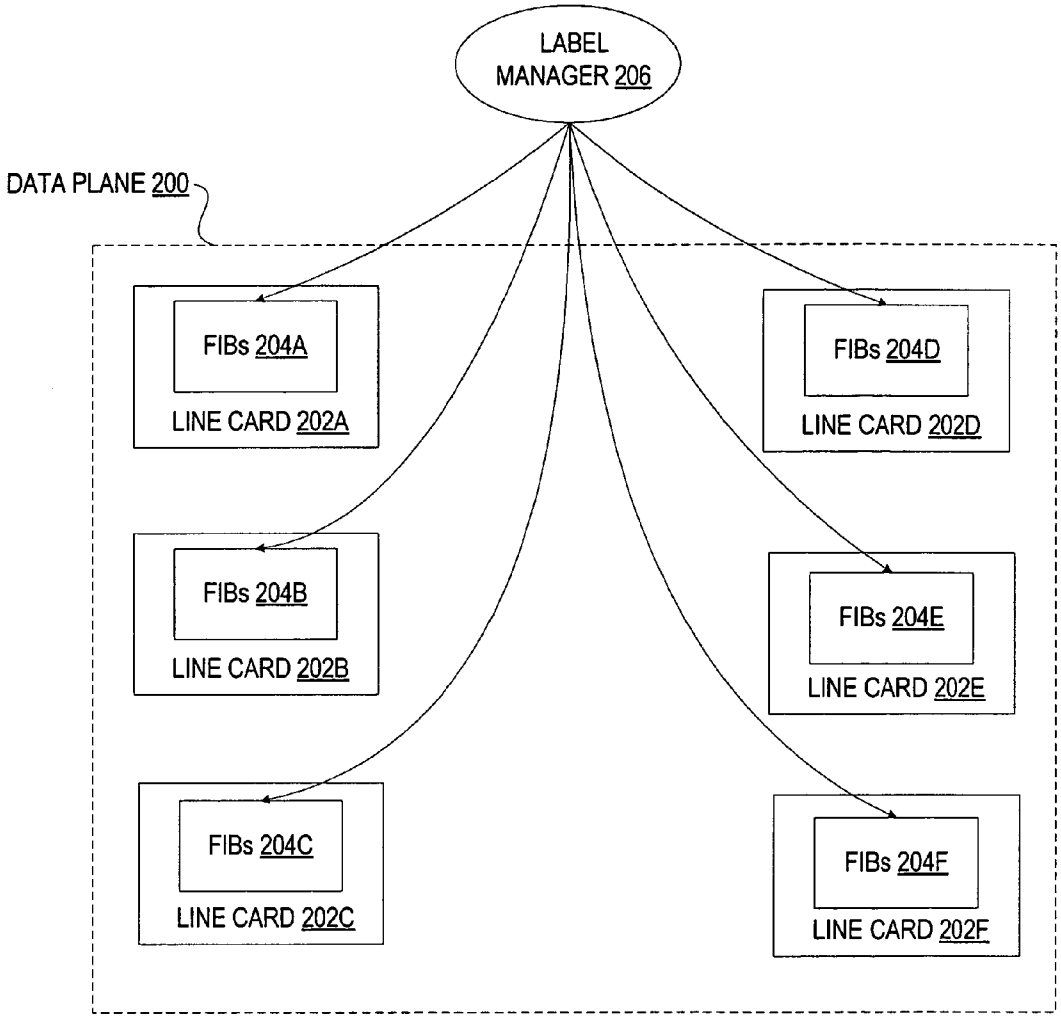
37 Claims, 13 Drawing Sheets





110
R1
114
PE2
MPLS NETWORK 100
L2
102
112
L5
P2
122
108
S1
PE1
R3
L1
P1
L4
PE4
120
L3
118
R4
116
PE3
106
104
R2

FIG. 1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DATA PLANE 200
FIBs 204A
LINE CARD 202A
FIBs 204B
LINE CARD 202B
FIBs 204C
LINE CARD 202C
FIBs 204D
LINE CARD 202D
FIBs 204E
LINE CARD 202E
FIBs 204F
LINE CARD 202F

FIG. 2

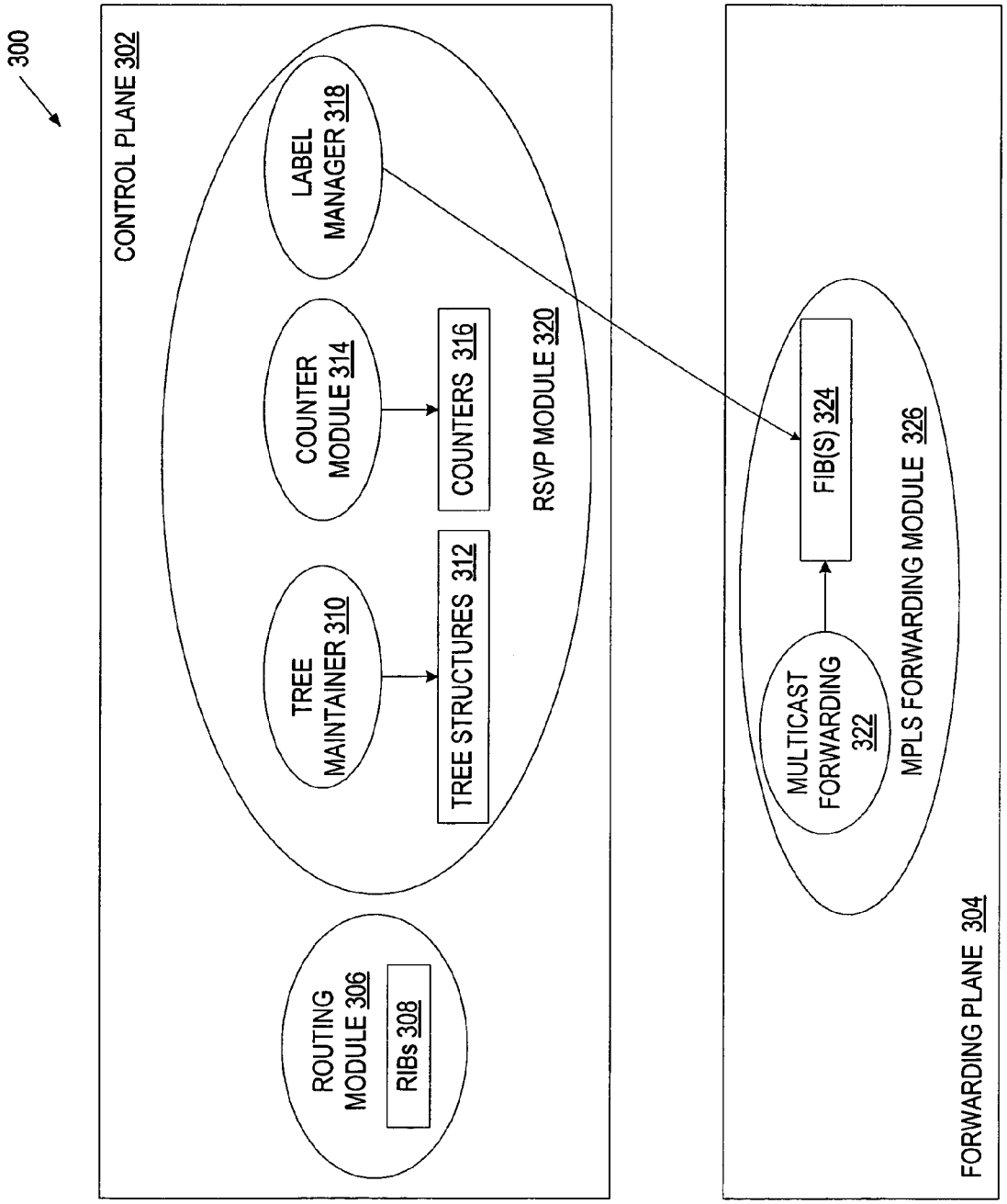
300
CONTROL PLANE 302
LABEL MANAGER 318
COUNTER MODULE 314
COUNTERS 316
TREE MAINTAINER 310
TREE STRUCTURES 312
RSVP MODULE 320
ROUTING MODULE 306
RIBs 308
FIB(S) 324
MULTICAST FORWARDING 322
MPLS FORWARDING MODULE 326
FORWARDING PLANE 304

FIG. 3

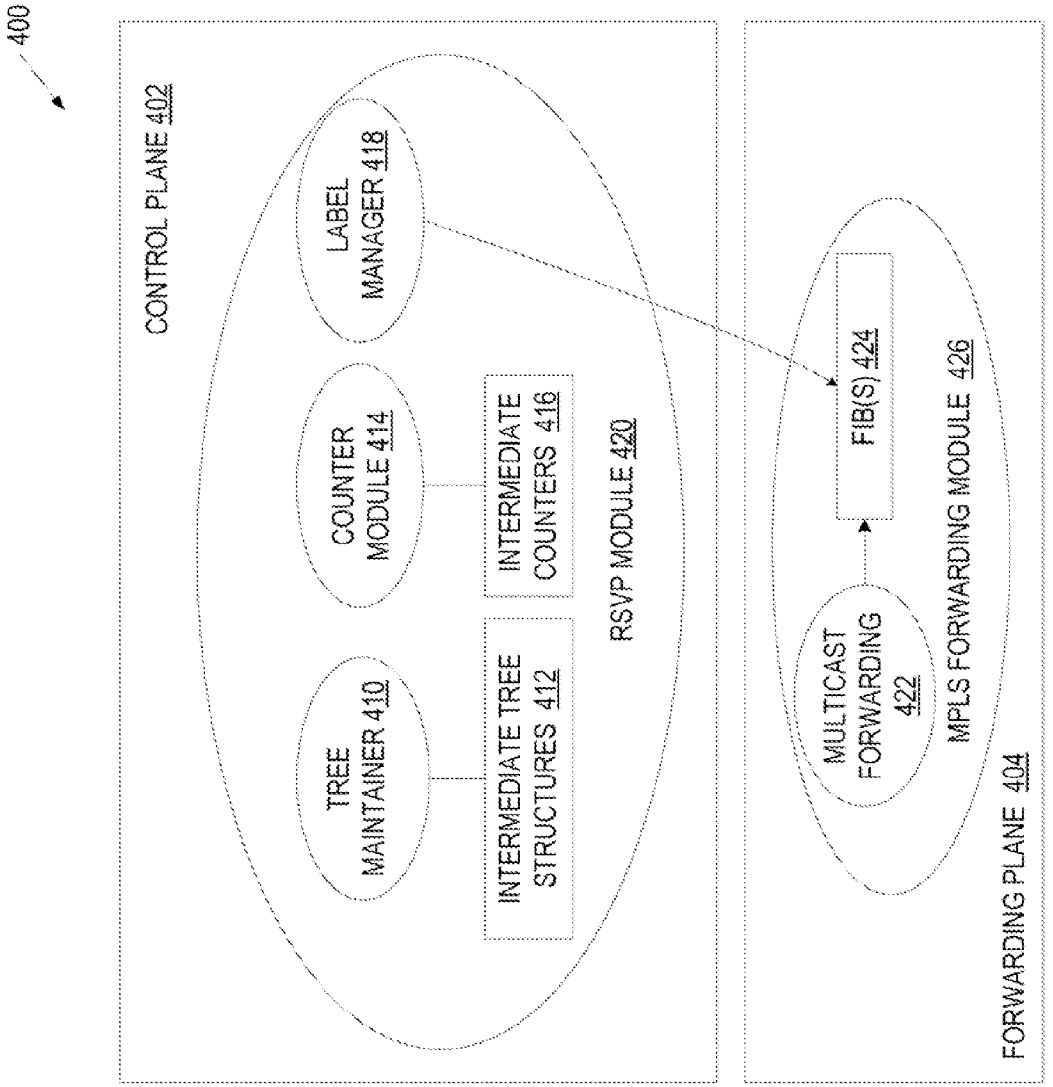
400
CONTROL PLANE 402
TREE MAINTAINER 410
COUNTER MODULE 414
LABEL MANAGER 418
INTERMEDIATE TREE STRUCTURES 412
INTERMEDIATE COUNTERS 416
RSVP MODULE 420
FIB(S) 424
MULTICAST FORWARDING 422
MPLS FORWARDING MODULE 426
FORWARDING PLANE 404

FIG. 4

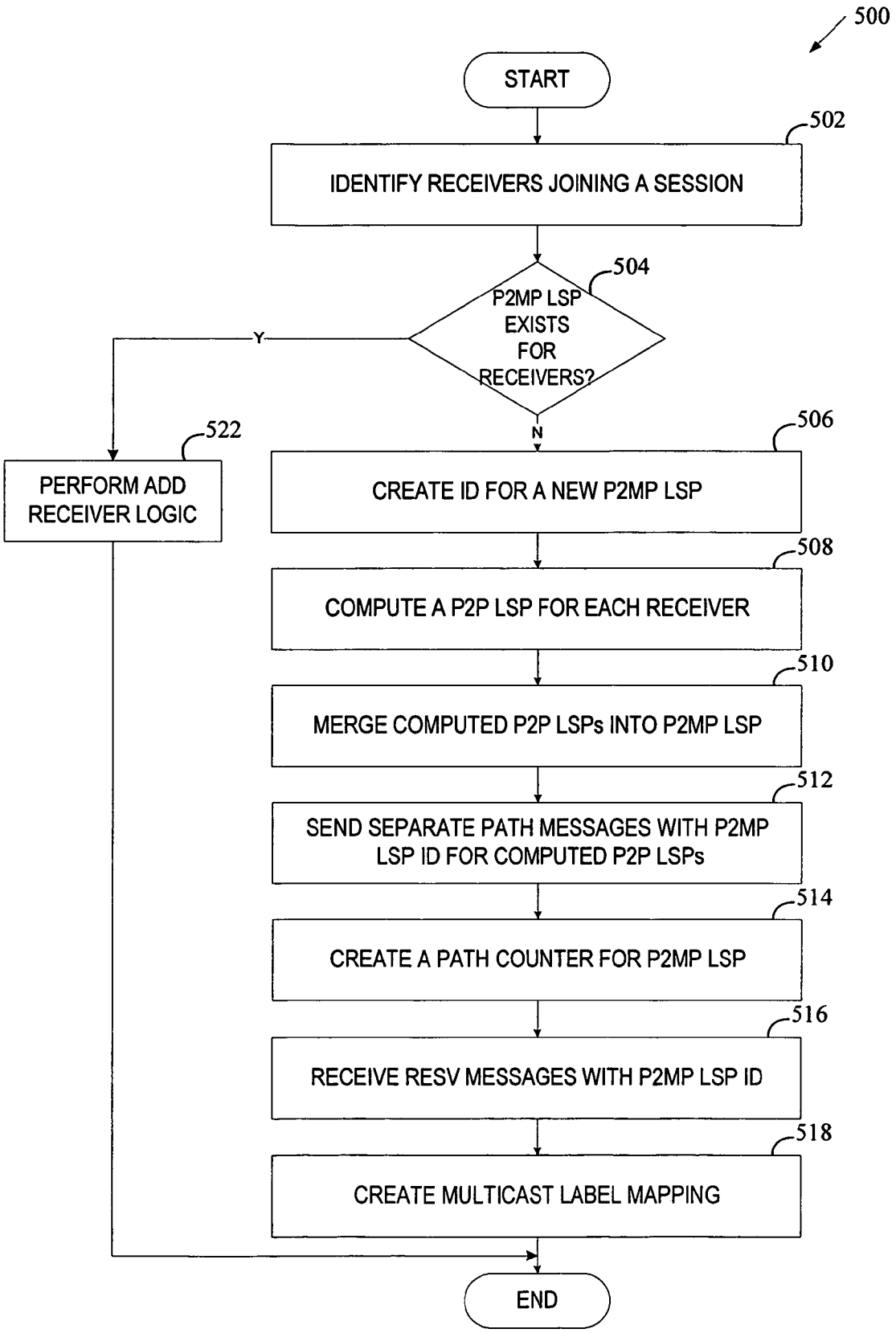
500
START
502
IDENTIFY RECEIVERS JOINING A SESSION
504
P2MP LSP EXISTS FOR RECEIVERS?
Y
N
522
PERFORM ADD RECEIVER LOGIC
506
CREATE ID FOR A NEW P2MP LSP
508
COMPUTE A P2P LSP FOR EACH RECEIVER
510
MERGE COMPUTED P2P LSPs INTO P2MP LSP
512
SEND SEPARATE PATH MESSAGES WITH P2MP LSP ID FOR COMPUTED P2P LSPs
514
CREATE A PATH COUNTER FOR P2MP LSP
516
RECEIVE RESV MESSAGES WITH P2MP LSP ID
518
CREATE MULTICAST LABEL MAPPING
END

FIG. 5A

550

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          SPE ADDRESS                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    MUST BE ZERO             |          TUNNEL ID              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           P2MP ID                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

FIG. 5B

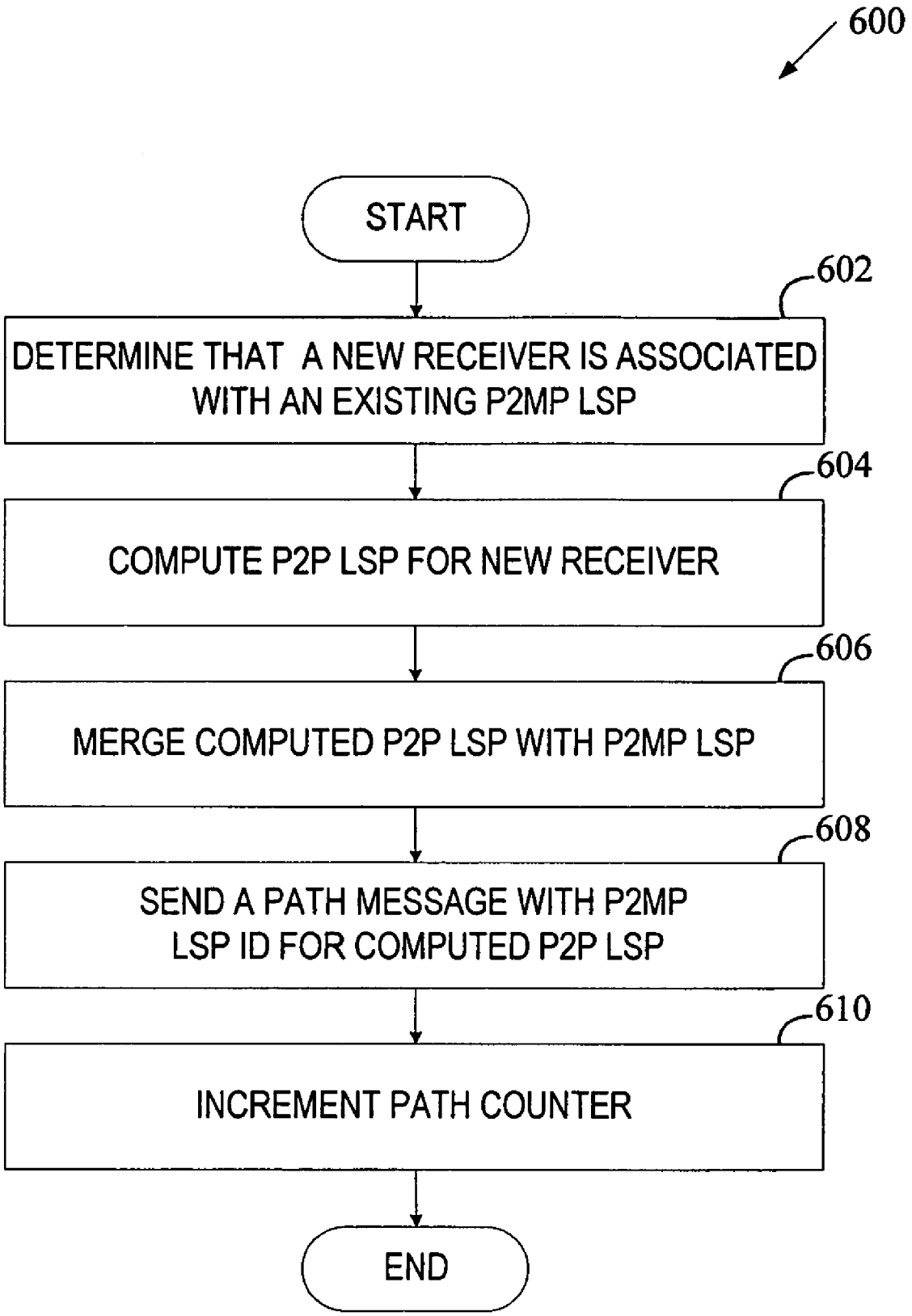
600
START
602
DETERMINE THAT A NEW RECEIVER IS ASSOCIATED WITH AN EXISTING P2MP LSP
604
COMPUTE P2P LSP FOR NEW RECEIVER
606
MERGE COMPUTED P2P LSP WITH P2MP LSP
608
SEND A PATH MESSAGE WITH P2MP LSP ID FOR COMPUTED P2P LSP
610
INCREMENT PATH COUNTER
END

FIG. 6

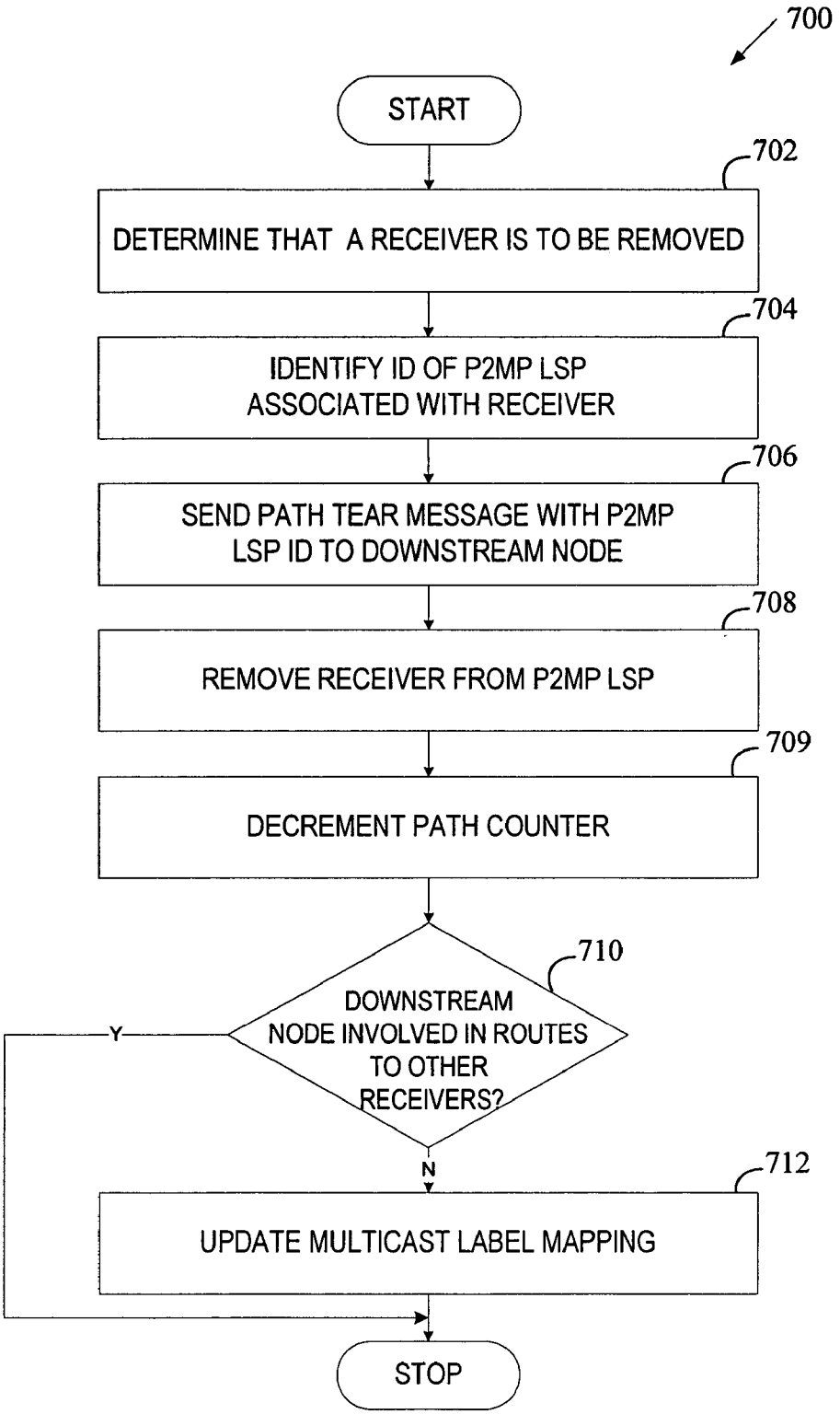
700
START
702
DETERMINE THAT A RECEIVER IS TO BE REMOVED
704
IDENTIFY ID OF P2MP LSP ASSOCIATED WITH RECEIVER
706
SEND PATH TEAR MESSAGE WITH P2MP LSP ID TO DOWNSTREAM NODE
708
REMOVE RECEIVER FROM P2MP LSP
709
DECREMENT PATH COUNTER
710
DOWNSTREAM NODE INVOLVED IN ROUTES TO OTHER RECEIVERS?
Y
N
712
UPDATE MULTICAST LABEL MAPPING
STOP

FIG. 7

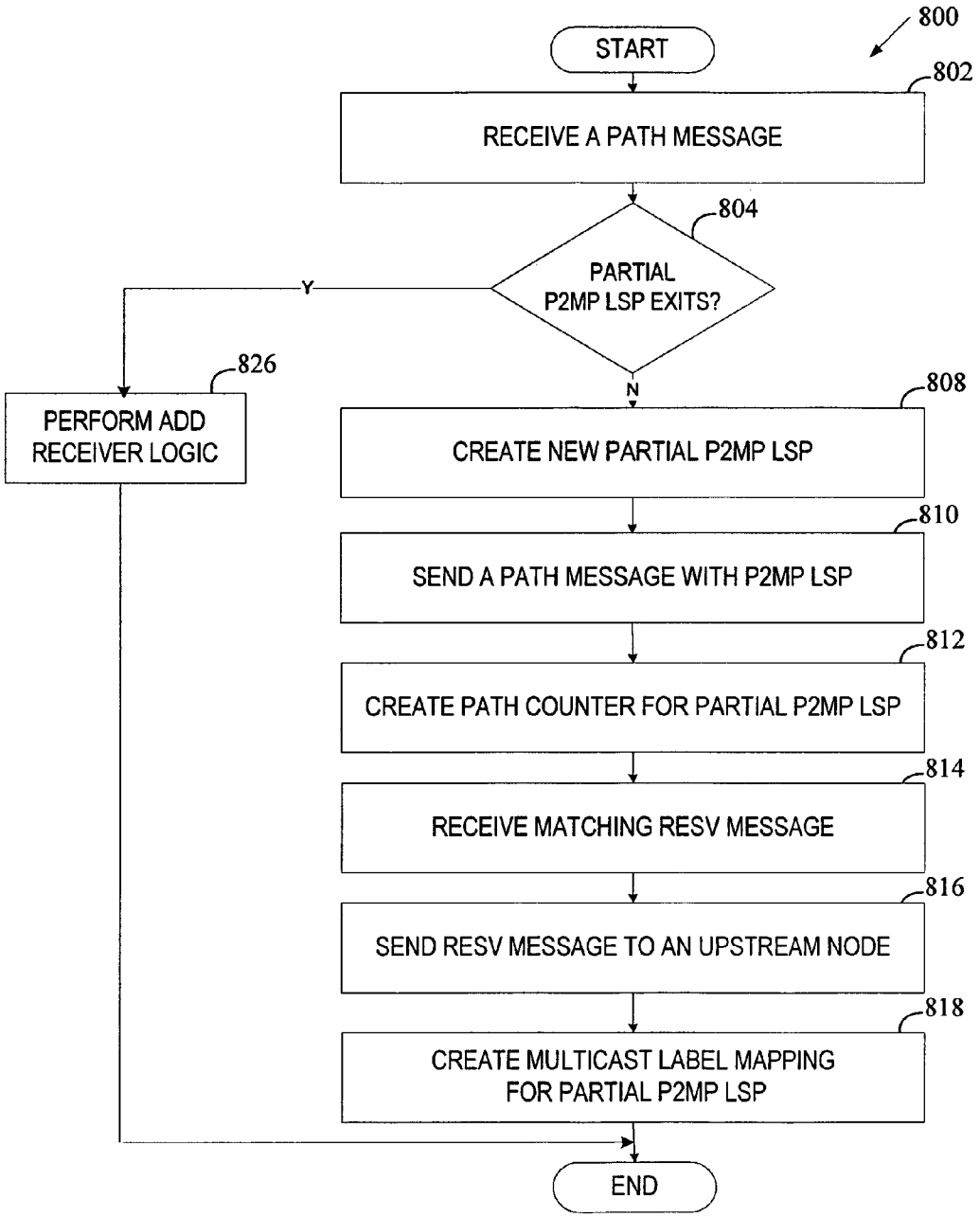
800
START
802
RECEIVE A PATH MESSAGE
804
PARTIAL
P2MP LSP EXITS?
Y
N
826
PERFORM ADD
RECEIVER LOGIC
808
CREATE NEW PARTIAL P2MP LSP
810
SEND A PATH MESSAGE WITH P2MP LSP
812
CREATE PATH COUNTER FOR PARTIAL P2MP LSP
814
RECEIVE MATCHING RESV MESSAGE
816
SEND RESV MESSAGE TO AN UPSTREAM NODE
818
CREATE MULTICAST LABEL MAPPING
FOR PARTIAL P2MP LSP
END

FIG. 8

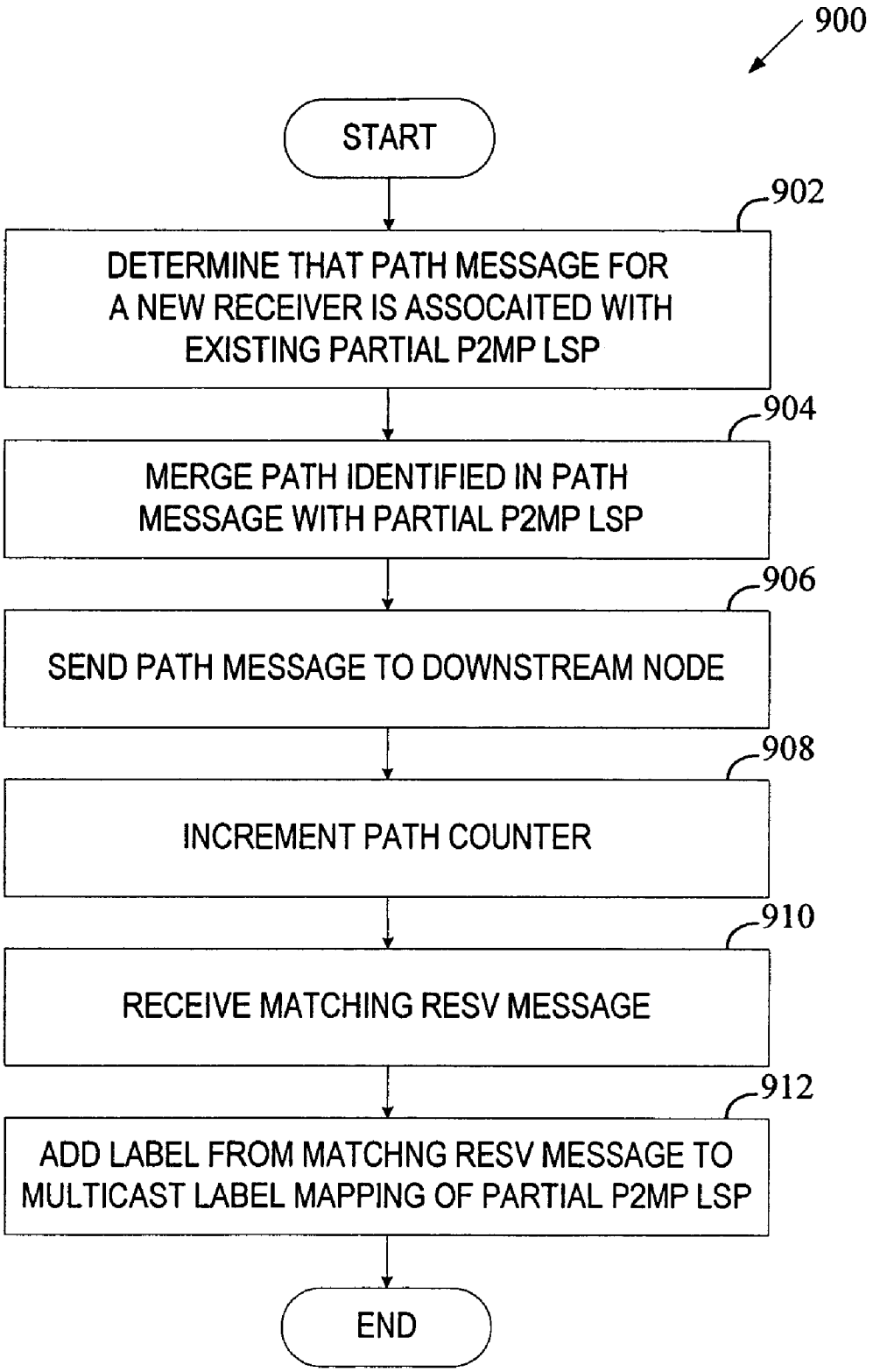
900
START
902
DETERMINE THAT PATH MESSAGE FOR A NEW RECEIVER IS ASSOCAITED WITH EXISTING PARTIAL P2MP LSP
904
MERGE PATH IDENTIFIED IN PATH MESSAGE WITH PARTIAL P2MP LSP
906
SEND PATH MESSAGE TO DOWNSTREAM NODE
908
INCREMENT PATH COUNTER
910
RECEIVE MATCHING RESV MESSAGE
912
ADD LABEL FROM MATCHNG RESV MESSAGE TO MULTICAST LABEL MAPPING OF PARTIAL P2MP LSP
END

FIG. 9

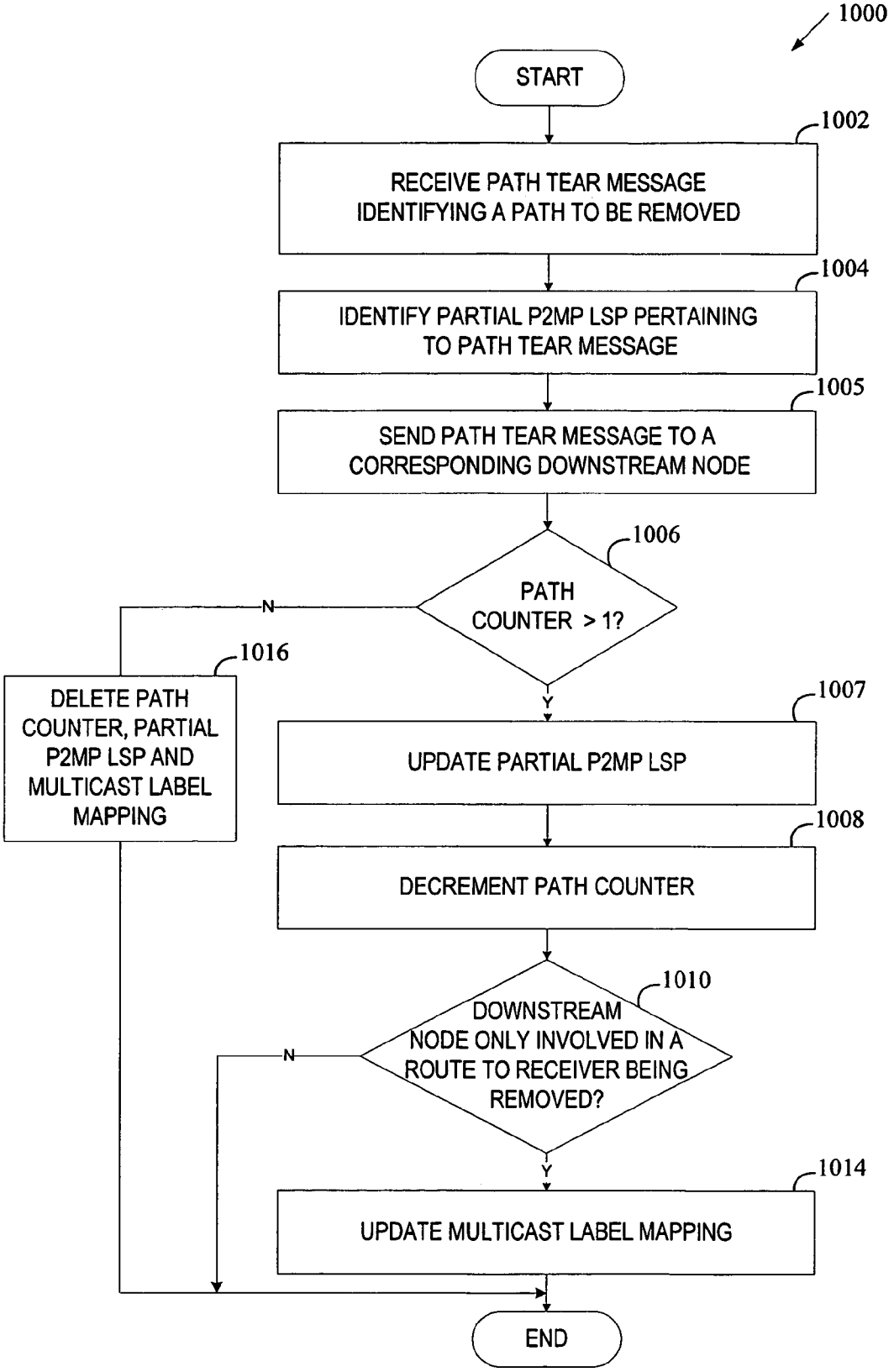
1000
START
1002
RECEIVE PATH TEAR MESSAGE IDENTIFYING A PATH TO BE REMOVED
1004
IDENTIFY PARTIAL P2MP LSP PERTAINING TO PATH TEAR MESSAGE
1005
SEND PATH TEAR MESSAGE TO A CORRESPONDING DOWNSTREAM NODE
1006
PATH COUNTER > 1?
N
Y
1016
DELETE PATH COUNTER, PARTIAL P2MP LSP AND MULTICAST LABEL MAPPING
1007
UPDATE PARTIAL P2MP LSP
1008
DECREMENT PATH COUNTER
1010
DOWNSTREAM NODE ONLY INVOLVED IN A ROUTE TO RECEIVER BEING REMOVED?
N
Y
1014
UPDATE MULTICAST LABEL MAPPING
END

FIG. 10

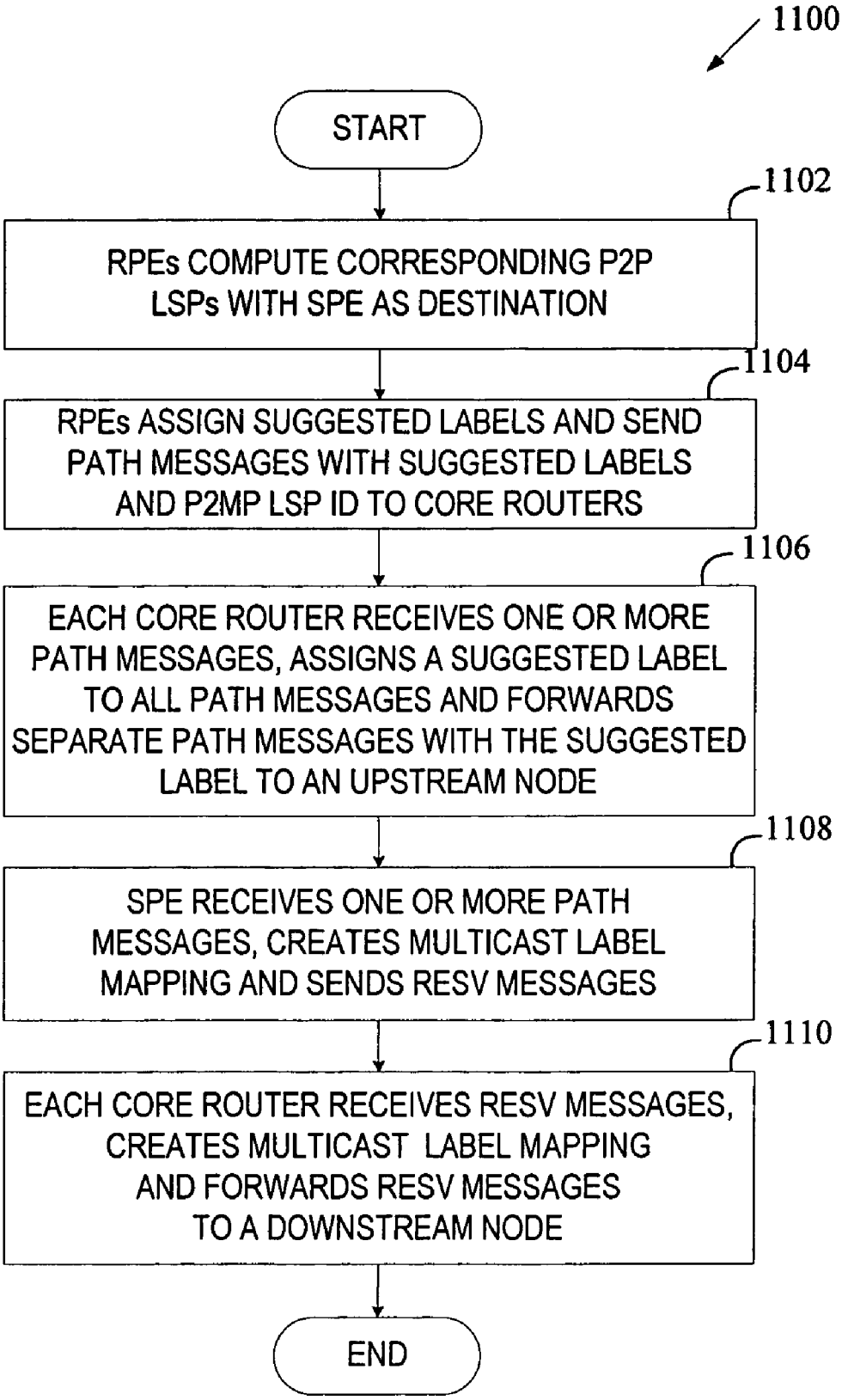
1100
START
1102
RPEs COMPUTE CORRESPONDING P2P LSPs WITH SPE AS DESTINATION
1104
RPEs ASSIGN SUGGESTED LABELS AND SEND PATH MESSAGES WITH SUGGESTED LABELS AND P2MP LSP ID TO CORE ROUTERS
1106
EACH CORE ROUTER RECEIVES ONE OR MORE PATH MESSAGES, ASSIGNS A SUGGESTED LABEL TO ALL PATH MESSAGES AND FORWARDS SEPARATE PATH MESSAGES WITH THE SUGGESTED LABEL TO AN UPSTREAM NODE
1108
SPE RECEIVES ONE OR MORE PATH MESSAGES, CREATES MULTICAST LABEL MAPPING AND SENDS RESV MESSAGES
1110
EACH CORE ROUTER RECEIVES RESV MESSAGES, CREATES MULTICAST LABEL MAPPING AND FORWARDS RESV MESSAGES TO A DOWNSTREAM NODE
END

FIG. 11

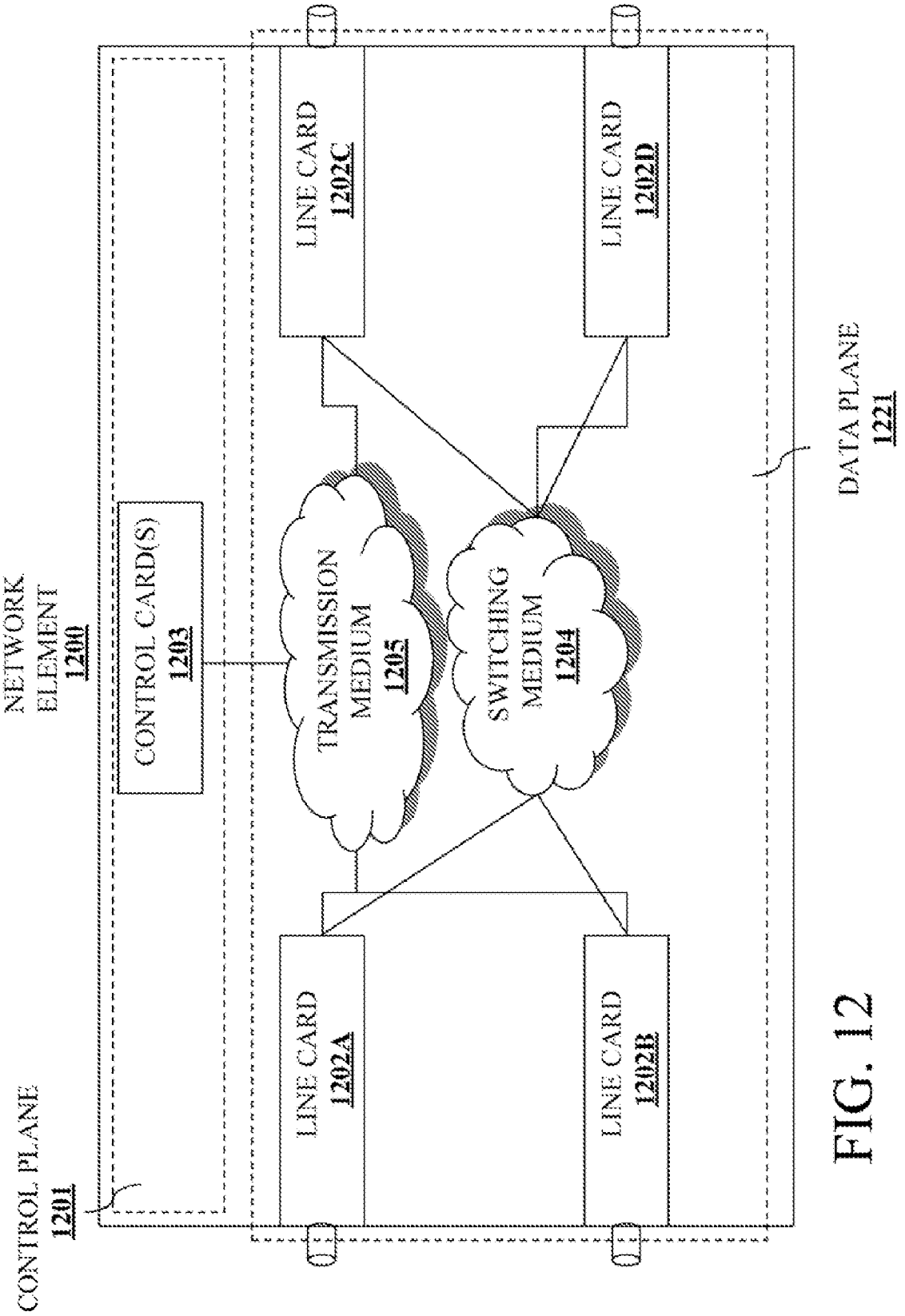
NETWORK ELEMENT 1200
CONTROL PLANE 1201
CONTROL CARD(S) 1203
LINE CARD 1202A
LINE CARD 1202B
LINE CARD 1202C
LINE CARD 1202D
TRANSMISSION MEDIUM 1205
SWITCHING MEDIUM 1204
DATA PLANE 1221

FIG. 12

MPLS TRAFFIC ENGINEERING FOR POINT-TO-MULTIPOINT LABEL SWITCHED PATHS

RELATED APPLICATIONS

The present application claims priority to U.S. Provisional Application Ser. No. 60/541,892, filed Feb. 3, 2004, which is incorporated herein in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to the field of communication. More specifically, the invention relates to providing point-to-multipoint label switch paths (LSPs) in a Multi-Protocol Label Switching (MPLS) network.

2. Background of The Invention

The multi-protocol label switching (MPLS) protocol may be categorized as a network layer protocol of the Open Standards Institute (OSI) reference model. MPLS provides a method for generically tunneling data through networks with label switched paths (LSPs). MPLS forwards data using labels that are attached to each data packet. These labels are distributed between the nodes that comprise the network.

Extended Resource Reservation Protocol referred to as RSVP Traffic Engineering (RSVP-TE) may be used as a signaling protocol to establish LSPs in the MPLS network. Generic RSVP uses a message exchange to reserve resources across a network for IP flows. RSVP-TE enhances generic RSVP so that it can be used to distribute MPLS labels and to establish traffic engineered (TE) LSPs that can be automatically routed away from network failures, congestion and bottlenecks and satisfy various other policies related to network performance optimization. TE LSPs typically carry a set of flows aggregated by their service class.

While RSVP-TE defines a mechanism for setting up point-to-point (P2P) TE LSPs, it does not provide a mechanism for building point-to-multipoint (P2MP) TE LSPs. A P2MP LSP is a label switched path that has one unique ingress label switching router (LSR) and multiple egress LSRs.

P2MP technology becomes increasingly important with the growing popularity of real-time applications such as content delivery services and video conferences that require P2MP real-time transmission capability with much more bandwidth and stricter quality of service (QoS) than non-real-time applications.

Seisho Yasukawa and Allan Kullberg have recently proposed protocol extensions to RSVP-TE for P2MP MPLS in the publication entitled "Extended RSVP-TE for Point-to-Multipoint LSP Tunnels." The proposed protocol extensions provide for signaling the P2MP LSP using a tree explicit route object that describes the P2MP tree topology. The P2MP tree is calculated and signaled as the tree explicit route object all LSRs participating in a session. If a new receiver is added to the session or an existing receiver is removed from the session, the whole tree is recomputed, an old tree is deleted, and the recomputed tree is signaled to the participating LSRs.

The approach of Yasukawa, et al., has a number of limitations. Specifically, in a large network, receivers are typically added to the session and removed from the session rather frequently. Each time such a change happens, the P2MP tree has to be recomputed and re-distributed to the participating nodes, thus creating a significant overhead.

In addition, if the use of a new P2MP tree begins before all copies of an old P2MP are deleted, a race condition may occur in the MPLS network. RSVP-TE does not provide support for

resolving a race condition caused by the existence of the two trees in the network. Hence, an additional mechanism is needed to address such race conditions.

Further, this approach significantly increases the size of messages exchanged by the LSRs in the MPLS network because the P2MP tree has to be sent to each LSR along the P2MP LSP.

BRIEF SUMMARY OF THE INVENTION

A method and apparatus for providing point-to-multipoint label switch paths (LSPs) in a Multi-Protocol Label Switching (MPLS) network is described.

According to one aspect of the invention, a point-to-multipoint LSP is built in a MPLS network by using Resource Reservation Protocol Traffic Engineering (RSVP-TE) to signal the point-to-multipoint LSP as separate point-to-point LSPs and to merge the separate point-to-point LSPs into the point-to-multipoint LSP.

These and other aspects of the present invention will be better described with reference to the Detailed Description and the accompanying Figures.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may best be understood by referring to the following description and accompanying drawings that are used to illustrate embodiments of the invention. In the drawings:

FIG. **1** is a block diagram of an exemplary MPLS network in which embodiments of the present invention can operate;

FIG. **2** is a block diagram illustrating an exemplary data plane of a network device, according to one embodiment of the present invention;

FIG. **3** is a block diagram of an exemplary edge router according to one embodiment of the present invention;

FIG. **4** is a block diagram of an exemplary core router according to one embodiment of the present invention;

FIG. **5**A is a flow diagram of one embodiment of a source edge router initiated process for building a P2MP LSP;

FIG. **5**B illustrates the format of an exemplary P2MP LSP session object;

FIG. **6** is a flow diagram of one embodiment of a source edge router initiated process for adding a new receiver to a P2MP LSP;

FIG. **7** is a flow diagram of one embodiment of a source edge router initiated process for removing a receiver from a P2MP LSP;

FIG. **8** is a flow diagram of one embodiment of a process for building a partial P2MP LSP;

FIG. **9** is a flow diagram of one embodiment of a process for adding a path to a partial P2MP LSP;

FIG. **10** is a flow diagram of one embodiment of a process for removing a path from a partial P2MP LSP;

FIG. **11** is a flow diagram of one embodiment of a receiver edge router initiated process for building a P2MP LSP; and

FIG. **12** is a block diagram of an exemplary network element according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, numerous specific details are set forth to provide a thorough understanding of the invention. However, it is understood that the invention may be practiced without these specific details. In other instances, well-known circuits, structures, standards, and techniques have not been shown in detail in order not to obscure the invention.

A method and apparatus for providing point-to-multipoint (P2MP) label switch paths (LSPs) in a Multi-Protocol Label Switching (MPLS) network is described. In one embodiment, extended Resource Reservation Protocol known as RSVP Traffic Engineering (RSVP-TE) is used to signal a P2MP LSP as separate point-to-point (P2P) LSPs associated with multiple receivers participating in a session. The separate P2P LSPs are then merged into a P2MP LSP using RSVP semantics. In one embodiment, each P2MP LSP is associated with a unique identifier that is used to recognize all the P2P LSPs belonging to the same P2MP LSP.

FIG. **1** is a block diagram of an exemplary MPLS network in which embodiments of the present invention can operate.

Referring to FIG. **1**, an MPLS network includes a set of label-switched routers (LSRs) consisting of edge routers (e.g., PE**1** **112** through PE**4** **118**) and core routers (e.g., P**1** **120** and P**2** **122**). An edge router forwards packets between an external device and the MPLS network **100**. A core router forwards packets to LSRs within the MPLS network **100**.

As shown in FIG. **1**, the edge router **112** receives packets from a source **102**. Each packet received from the source **102** is replicated within the MPLS network **100** and sent to each of the receivers **104** through **110**. The source **102** and each of the receivers **104** through **110** may be any device and/or network connected to the MPLS network **100**.

The packets are replicated based on a P2MP LSP that is established from the source **102** to the receivers **104**, **106**, **108** and **110**. The P2MP LSP is established using RSVP-TE. As discussed above, RSVP is a signaling protocol that uses a message exchange to reserve resources across a network for IP flows. RSVP-TE enhances generic RSVP so that is can be used to distribute MPLS labels and to establish traffic engineered (TE) LSPs that can be automatically routed away from network failures, congestion and bottlenecks and satisfy various other policies related to network performance optimization. RSVP-TE defines a mechanism for setting up point-to-point (P2P) LSPs using PATH and RESV messages. In one embodiment, this mechanism is used to build multiple P2P LSPs for the receivers **104**, **106**, **108** and **110**. The multiple P2P LSPs are then merged into a P2MP LSP based on a mechanism for merging unicast paths that is supported by generic RSVP.

In one embodiment, each created P2MP LSP is assigned a unique identifier that is included in every PATH or RESV message exchanged by the nodes of the MPLS network **100**. Hence, P2P LSPs belonging to the same P2MP LSP can share network resources.

In one embodiment, each node in the MPLS network **100**, that receives PATH and RESV messages associated with the P2MP LSP, creates a multicast label mapping for a portion of the P2MP LSP that covers this node. A multicast label mapping identifies an incoming label and one or more outgoing labels for the node. For example, a multicast label mapping of the core router **120** may be expressed as (L**1**=>{L**3**, L**4**}).

In one embodiment, the establishment of the P2P LSPs is initiated by an edge router **112** connected to the source **102**. The edge router **112** is referred to herein as a source edge router, and edge routers **114**, **116** and **118** that are connected to the receivers **104** through **110** are referred to herein as receiver edge routers. In this embodiment, the source edge router **112** computes a P2P LSP to each of the receiver edge routers **114**, **116** and **118** and sends separate PATH messages identifying corresponding P2P LSPs to the core routers **120** and **122**. In one embodiment, each PATH message contains a unique identifier of the P2MP LSP to which the P2P LSPs belong.

The core router **120** processes the PATH message and forwards two separate PATH messages to the receiver edge routers **116** and **118**. The first PATH message identifies a route from the core router **120** to the receiver edge router **116** and the second PATH message identifies a route from the core router **120** to the receiver edge router **118**. Similarly, the core router **122** forwards a PATH message to the receiver edge router **114**.

The receiver edge routers **114**, **116** and **118** respond with RESV messages that include labels allocated by the receiver edge routers. The core router **120** receives RESV messages from the receiver edge routers **116** and **118** with labels L**3** and L**4** respectively, allocates a new label L**1**, creates a multicast mapping of (L**1**=>{L**3**, L**4**}), and forwards an RESV message with label L**1** to the source edge router **112**. In one embodiment, the core router **120** forwards a separate RESV message in response to each received RESV.

The core router **122** receives an RESV message from the receiver edge router **114** with label L**2**, creates a new label L**5**, creates a multicast mapping of (L**5** =>{L**2**}), and forwards an RESV message with label L**5** to the source edge router **112**.

The source edge router **112** receives RESV messages from core routers **120** and **122** and populates an Forwarding Equivalence Class (FEC) table (e.g., using a designated non-RSVP mechanism) with a mapping of (Destination IP Address =>{L**1**, L**5**}).

In another embodiment, the establishment of the P2P LSPs is initiated by receiver edge routers **114**, **116** and **118**. In particular, each of the receiver edge routers **114**, **116** and **118** computes a P2P LSP with the source edge router **112** as a destination and sends a PATH message identifying a corresponding P2P LSP and a suggested label. In one embodiment, each PATH message contains a unique identifier of the P2MP LSP to which the P2P LSPs belong.

The router **120** receives PATH messages from the receiver edge routers **116** and **118**, assigns a suggested label L**1** to each of them, and forwards two separate PATH messages to the source edge router **112**. The core router **122** receives a PATH message from the receiver edge router **114** and forwards it to the source edge router **112**.

The source edge router **112** creates a multicast label mapping of ({L**1**, L**2**}) and sends RESV messages to the core routers **120** and **122**. In one embodiment, the source edge router **112** sends a separate RESV message in response to each PATH message received from the core router **120**. In another embodiment, the source edge router **112** sends a single RESV message in response to both PATH messages received from the core router **120**.

Once the core routers **120** and **122** receive their RESV messages, they create multicast mappings and send RESV messages to corresponding receiver edge routers **114**, **116** and **118** that create their own multicast label mappings.

In both source and receiver edge router initiated embodiments, when a new receiver needs to be added, a P2P LSP is established for the new receiver and the established P2P LSP is then merged with the existing P2P LSPs in the P2MP LSP using the RSVP mechanism for merging unicast paths. When an existing receiver needs to be removed, an RSVP PATH TEAR message is used to remove the path to this receiver from the P2MP LSP.

Accordingly, embodiments of the present invention follow existing RSVP-TE procedures with relatively minor enhancements and do not cause a significant increase in the size of messages exchanged between the LSRs.

FIG. **2** is a block diagram illustrating an exemplary data plane **200** of a network device, according to one embodiment of the present invention. The network device may be any LSR

in the MPLS network **100**. The data plane **200** includes a number of line cards such as line cards **202**A through **202**F. The line cards **202**A through **202**F host forwarding information bases (FIBs) **204**A through **204**F respectively. The FIBs **204**A through **204**F contain multicast label mappings for different P2MP LSPs passing through the line cards **202**A through **202**F. The multicast label mappings are created by a label manager **206** using labels included in the RSVP-TE signaling messages exchanged between this network device and other network devices in the MPLS network **100**, as discussed in more detail above. The label manager **206** resides on the control plane of the network device. In one embodiment, the label manager **206** is a component of an RSVP module, as will be discussed in greater detail below. Multicast label mappings may be stored using various formats (e.g., as a table, as a balanced hash-based tree with a linked list of nodes to store multiple labels when necessary, etc.).

The multicast forwarding mappings are used by an MPLS forwarding module to identify interfaces to which every incoming packet needs to be sent and labels to be included in these packets.

While FIG. **2** shows one exemplary embodiment of the data plane, alternative embodiments may be implemented differently (e.g., with more line cards, less line cards, or a single line card).

FIG. **3** is a block diagram of an exemplary edge router **300** according to one embodiment of the present invention.

Referring to FIG. **3**, the control plane **302** of the edge router **300** hosts a routing module **306** and an RSVP module **320**. The routing module **306** is responsible for computing a separate P2P LSP for each receiver participating in a session, for associating each P2P LSP with the unique ID of the P2MP LSP to which the P2P LSP belongs, and for storing the computed P2P LSPs in one or more routing information bases (RIBs) **308**. In one embodiment, the routing module **306** calculates the P2P LSPs of the same P2MP LSP so that they can share resources (e.g., links, QoS, etc.) where possible. These calculations may be performed using IP routing protocols with TE extensions, such as Intermediate System to Intermediate System Traffic Engineering (ISIS-TE), Open Shortest Path First Traffic Engineering (OSPF-TE), etc.

The RSVP module **320** may include a tree maintainer **310**, a counter module **314**, and a label manager **318** (such as a label manager **206** of FIG. **2**). The tree maintainer **310** is responsible for merging the separate P2P ISPs computed by the routing module **306** into a P2MP LSP using the RSVP mechanism to merge unicast paths and for updating the P2MP LSP when a new receiver joins the session or an existing receiver is removed from the session, as will be discussed in more detail below. Various formats may be used to store information about P2MP LSPs created by the tree maintainer **310**. For example, each P2MP LSP can be stored as a tree data structure **312**.

The counter module **314** is responsible for maintaining a path counter **316** for each P2MP LSP. A path counter **316** specifies the number of P2P LSPs in the P2MP LSP. The counter module **314** increments the path counter each time a new P2P LSP is established for the P2MP LSP. Similarly, the path counter is decremented each time an existing P2P LSP is removed from the P2MP LSP.

The label manager **318** is responsible for creating a multicast label mapping for each P2MP LSP initiating from the edge router **300** based on labels specified in the signaling messages exchanged between the edge router **300** and the other nodes along the P2MP LSP.

The forwarding plane **304** may exist on multiple line cards of the network device **300**. The forwarding plane **304** hosts an MPLS forwarding module **326** that may include a multicast forwarding **322** and FIBs **324**. FIBs **324** store multicast label mappings generated by the label manager **318**. The multicast forwarding **322** is responsible for determining one or more interfaces to which each incoming packet is to be sent. In one embodiment, the multicast forwarding **322** makes this determination using multicast label mapping information in the FIBs **324**. If the packet needs to be sent out on multiple interfaces, the multicast forwarding **322** replicates the packet as needed, includes a corresponding label specified by the multicast label mapping in each replicated packet, and sends each replicated packet to the appropriate interface.

While FIG. **3** shows one exemplary embodiment of the edge router, alternative embodiments may be implemented differently (e.g., having a different configuration, more or less modules or data structures, etc.).

FIG. **4** is a block diagram of an exemplary core router **400** according to one embodiment of the present invention.

Referring to FIG. **4**, the control plane **402** of the core router **400** hosts an RSVP module **420** that may include a tree maintainer **410**, a counter module **414**, and a label manager **418**. The tree maintainer **410** is responsible for merging the portions of P2P LSPs that cover routes from the core router **400** to one or more receivers that belong to the same P2MP LSP. The merge is performed using the RSVP unicast path merge mechanism. The merge results in a partial (or intermediate) P2MP LSP. The tree maintainer **410** updates the partial P2MP LSP each time a new route from the core router **400** to a new receiver needs to be added or an existing route from the core router **400** to an existing receiver needs to be removed. A partial P2MP LSP may be stored using various formats. For example, a partial P2MP LSP may be stored as a tree (e.g., an intermediate tree data structure **412** in FIG. **4**).

The counter module **414** is responsible for maintaining a path counter **416** for each partial P2MP LSP identified in the data structures **412**. A path counter **416** specifies the number of routes in the partial P2MP LSP. The counter module **414** increments the path counter **416** each time a new route is added to the partial P2MP LSP. Similarly, the path counter **416** is decremented each time an existing route is removed from the partial P2MP LSP.

The label manager **418** is responsible for creating a multicast label mapping for each partial P2MP LSP maintained in the core router **400** based on labels specified in the signaling messages exchanged between the core router **400** and other nodes along the partial P2MP LSP.

The forwarding plane **404** hosts an MPLS forwarding module **426** that may include a multicast forwarding **422** and FIB(s) **424** that operate similarly to the MPLS forwarding module **326** discussed above in conjunction with FIG. **3**.

While FIG. **4** shows one exemplary embodiment of the core router, alternative embodiments may be implemented differently (e.g., having a different configuration, more or less modules or data structures, etc.).

FIGS. **5**A, **6** and **7** are flow diagrams of source edge router initiated processes performed by a source edge router according to various embodiments of the present invention. The process may be performed by processing logic that may comprise hardware (e.g., circuitry, dedicated logic, programmable logic, microcode, etc.), software (such as run on a general purpose computer system or a dedicated machine), or a combination of both.

FIG. **5**A is a flow diagram of one embodiment of a process **500** for building a P2MP LSP. Process **500** begins with processing logic identifying receivers that are joining the session

(processing block **502**). The identification may be performed using various means (e.g., by a protocol at the application level, by Protocol Independent Multicast (PIM) running by the Internet Service Provider, etc.).

Next, processing logic determines whether the identified receivers belong to an existing P2MP LSP (decision box **504**). In one embodiment, the determination is made by searching the identifiers of existing P2MP LSPs (P2MP LSP ID). In one embodiment, each P2MP LSP ID is composed of a unique combination of the address of a source edge router initiating the P2MP LSP, a tunnel ID that identifies the type of the traffic (e.g., video, voice, etc.) traveling along the P2MP LSP, and the identifier of the session. In one embodiment, a new P2MP LSP session RSVP-TE object is introduced to carry the elements of the P2MP LSP ID. FIG. **5**B illustrates the format of an exemplary P2MP LSP session object **550**, which contains the address of the source edge router (e.g., a 32-bit IPv4 (Internet Protocol version 4) address), the tunnel ID is a 16-bit identifier and the P2MP ID is a 32-bit identifier.

In one embodiment, a P2MP LSP session object is included in all signaling messages exchanged between the nodes of the MPLS network.

Referring again to FIG. **5**A, if the determination made at processing block **504** is positive, processing logic performs an add receiver process **522** discussed in more detail below in conjunction with FIG. **6**. Otherwise process **500** flows to processing block **506**, at which processing logic creates a unique identifier for a new P2MP LSP (processing block **506**). In one embodiment, the P2MP LSP ID is created as a P2MP LSP session object discussed above.

At processing block **508**, processing logic computes a P2P LSP for each receiver identified at processing block **502**. In one embodiment, the P2P LSPs are computed to share network resources where possible as discussed in more detail above.

At processing block **510**, processing logic merges the computed P2P LSPs into a P2MP LSP with the ID created at processing block **506**. As discussed above, the P2MP LSP may be stored as a tree or any other data structure.

At processing block **512**, processing logic sends a separate PATH message for each computed P2P LSP to a corresponding downstream node.

At processing block **514**, processing logic creates a path counter that specifies the number of P2P LSP in the P2MP LSP.

Further, processing logic receives RESV messages with the P2MP LSP ID (processing block **516**) and creates a multicast label mapping based on the labels specified in the RESV messages (processing block **518**). In one embodiment, processing logic receives a separate RESV message in response to each PATH message it previously sent unless an error has occurred (e.g., if a downstream node is down, etc.). In this embodiment, if the number of received RESV messages is lower than the number of previously sent PATH messages, then processing logic updates the P2MP LSP to remove the P2P LSPs for which RESV messages were not received. In addition, processing logic decrements the path counter by the number of missing RESV messages.

FIG. **6** is a flow diagram of one embodiment of a process **600** for adding a new receiver to a P2MP LSP. Process **600** begins with processing logic determining that the new receiver belongs to an existing P2MP LSP (decision box **602**). As discussed above, in one embodiment, the determination is made by searching the identifiers of existing P2MP LSPs (P2MP LSP ID).

At processing block **604**, processing logic computes a P2P LSP to reach the new receiver. As discussed above, in one embodiment, the P2P LSP is computed to share resources with other P2P LSPs that belong to the same P2MP LSP.

At processing block **606**, processing logic merges the computed P2P LSP with the other P2P LSPs of the P2MP LSP.

At processing block **608**, processing logic sends a PATH message for the computed P2P LSP to a corresponding downstream node.

At processing block **610**, processing logic increments the path counter associated with the P2MP LSP.

Further, in one embodiment, processing logic is supposed to receive a matching RESV message unless an error has occurred (e.g., if a downstream node is down, etc.). Then, if the matching RESV message is received, processing logic determines whether the label specified in the matching RESV message is already included in the multicast label mapping for the P2MP LSP. If not, processing logic updates the multicast label mapping to include this new label. If processing logic does not receive a matching RESV message, processing logic updates the P2MP LSP to remove the newly-added P2P LSP and decrements the path counter.

FIG. **7** is a flow diagram of one embodiment of a process **700** for removing a receiver from a P2MP LSP. Process **700** begins with processing logic determining that a receiver is to be removed from a session (processing block **702**). The identification may be performed using various means (e.g., by a protocol at the application level, by Protocol Independent Multicast (PIM) running by the Internet Service Provider, etc.).

Next, processing logic determines the identifier of the P2MP LSP to which the receiver belongs (processing block **704**). In one embodiment, the determination is made by searching identifiers of existing P2MP LSP IDs for the receiver's identifying information (e.g., the address of the source edge router, the tunnel ID and the identifier of the session).

At processing block **706**, processing logic sends a PATH TEAR message identifying the path to the receiver being removed and the P2MP LSP ID. In one embodiment, the PATH TEAR message includes a P2MP LSP session object with the P2MP LSP ID. In one embodiment, if more than one receiver needs to be removed, processing logic sends a separate PATH TEAR message for each of these receivers.

At processing block **708**, processing logic removes the path to this receiver from the P2MP LSP by updating the internal data structures, for example, by removing the receiver from a tree data structure.

At processing block **709**, processing logic decrements the path counter associated with the P2MP LSP.

At decision box **710**, processing logic determines whether an immediate downstream node is only involved in the route to the receiver being removed. If so, processing logic updates the multicast label mapping to remove the label associated with this downstream node (processing block **712**).

FIGS. **8**-**10** are flow diagrams of processes performed by a core router according to various embodiments of the present invention. The process may be performed by processing logic that may comprise hardware (e.g., circuitry, dedicated logic, programmable logic, microcode, etc.), software (such as run on a general purpose computer system or a dedicated machine), or a combination of both.

FIG. **8** is a flow diagram of one embodiment of a process **800** for building a partial P2MP LSP. Process **800** begins with processing logic receiving a PATH message (processing block **802**). The PATH message may be received from a source edge router or another core router.

At decision box **804**, processing logic determines whether the PATH message is associated with an existing partial P2MP LSP using the P2MP LSP ID included in the PATH

message. If so, an add receiver process **826** is performed that will be discussed in more detail in conjunction with FIG. **9**.

If an existing partial P2MP LSP does not exist, processing logic creates a new partial P2MP LSP based on the route specified in the PATH message (processing block **808**), sends a PATH messages to a downstream node identified in the received PATH message (processing block **810**), and creates an intermediate path counter for the partial P2MP LSP (processing block **812**). The intermediate path counter specifies the number of unicast paths in the partial P2MP LSP. In one embodiment, processing logic stores the partial P2MP LSP using a specific data structure (e.g., as a tree referred to herein as an intermediate tree).

Further, processing logic receives a matching RESV message (processing block **814**), forwards the RESV message to an upstream node (processing block **816**), and creates a multicast label mapping for the partial P2MP LSP (processing block **818**).

FIG. **9** is a flow diagram of one embodiment of a process **900** for adding a path to a partial P2MP LSP. Process **900** begins with processing logic receiving a PATH message and determining that the PATH message is associated with an existing partial P2MP LSP using the P2MP LSP ID included in the PATH message (processing block **902**).

At processing block **904**, processing logic merges the path identified in the PATH messages with the other unicast paths in the existing partial P2MP LSP.

Next, processing logic sends a PATH messages to a downstream node identified in the received PATH message (processing block **906**) and increments an intermediate path counter associated with the partial P2MP LSP (processing block **908**).

Further, processing logic receives a matching RESV message (processing block **910**) and updates a multicast label mapping of the partial P2MP LSP to include a new label that is specified in the received RESV message (processing block **912**).

Afterwards, in one embodiment, processing logic sends a RESV message to an upstream node in response to receiving the RESV from the downstream node.

FIG. **10** is a flow diagram of one embodiment of a process **1000** for removing a path from a partial P2MP LSP. Process **1000** begins with processing logic receiving a PATH TEAR message identifying a unicast path to be removed (processing block **1002**). In one embodiment, the PATH TEAR message includes an identifier of a corresponding P2MP LSP.

Next, processing logic identifies a partial P2MP LSP associated with the PATH TEAR message using the identifier of the P2MP LSP (processing block **1004**) and forwards the PATH TEAR message to a corresponding downstream node (processing block **1005**).

At decision box **1006**, processing logic determines whether an intermediate path counter associated with the partial P2MP LSP is greater than 1. If the intermediate path counter is equal to 1, then it indicates that the partial P2MP LSP only includes a path to the receiver that is being removed. Hence, processing logic deletes the partial P2MP LSP, as well as the intermediate path counter and the multicast label mapping associated with this partial P2MP LSP (processing block **1016**).

If the intermediate path counter is greater than 1, then processing logic removes the unicast path identified in the received PATH TEAR message from the partial P2MP LSP (processing block **1007**) and decrements the intermediate path counter (processing block **1008**).

Further, processing logic determines whether the downstream node to which the PATH TEAR message is forwarded is only involved in the path to the receiver being removed (decision box **1010**). If so, processing logic updates the multicast label mapping to remove the label associated with the downstream node (processing block **1014**).

FIG. **11** is a flow diagram of one embodiment of a receiver edge router initiated process for establishing a P2MP LSP. The process may be performed by processing logic that may comprise hardware (e.g., circuitry, dedicated logic, programmable logic, microcode, etc.), software (such as run on a general purpose computer system or a dedicated machine), or a combination of both.

Referring to FIG. **11**, process **1100** begins with processing logic in each receiver edge router computing a corresponding P2P LSP with a source edge router as a destination (processing block **1102**), assigning a suggested label and sending a PATH message with the label and the identifier of the P2MP LSP being built (processing block **1104**).

Next, processing logic in each core router along the computed P2P LSPs receives one or more PATH messages, assigns a suggested label to all received PATH messages, and forwards each PATH message with the assigned label to an upstream node (processing block **1106**).

Further, processing logic in the source edge router receives the PATH messages from one or more core routers, creates a multicast label mapping for the P2MP LSP, and sends RESV messages matching the PATH messages received (processing block **1108**).

Afterwards, processing logic in each core router receives one or more RESV messages, creates a multicast label mapping for the P2MP LSP, and forwards each RESV message to a downstream node (processing block **1110**).

FIG. **12** is a diagram of an exemplary network element according to one embodiment of the invention. Referring to FIG. **12**, the network element **1200** includes a set of control cards **1203** in the control plane **1201**. The control card(s) **1203** is coupled with a transmission medium **1205** (e.g., a system bus) in the data plane **1221**. The transmission medium **1205** is coupled with the line cards **1202**A-**1202**D. The transmission medium **1205** carries information from the control card(s) **1203** to the line cards **1202**A-**1202**D. The line cards **1202**A-**1202**D are coupled with each other via the switching medium **1204**. The switching medium **1204** may be a separate switching unit including hardware and/or software to determine which line card to forward traffic. Alternatively, the switching medium **1204** may be a mesh.

The control card(s) **1203** and the line cards **1202**A-**1202**D illustrated in FIG. **12** include memories, processors, and/or ASICs. Such memories include a machine-readable medium on which is stored a set of instructions (i.e., software) embodying any one, or all, of the methodologies described herein. Software can reside, completely or at least partially, within this memory and/or within the processor and/or ASICs. For the purpose of this specification, the term "machine-readable medium" shall be taken to include any mechanism that provides (i.e., stores and/or transmits) information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes read only memory ("ROM"), random access memory ("RAM"), magnetic disk storage media, optical storage media, flash memory devices, electrical, optical, acoustical, or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.), etc.

While FIG. **12** shows one exemplary embodiment of the network element, alternative embodiments may be implemented differently (e.g., having a different configuration, more or less control cards or line cards, etc.).

While the invention has been described in terms of several embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The method and apparatus of the invention can be practiced with modification and alteration within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of limiting on the invention.

We claim:

1. A method comprising:

building a point-to-multipoint label switch path (LSP) in a multi-protocol label switching (MPLS) network by using Resource Reservation Protocol Traffic Engineering (RSVP-TE) to signal the point-to-multipoint LSP as a plurality of separate point-to-point LSPs associated with a plurality of receivers participating in a session without transmitting a representation of the topology of the point-to-multipoint LSP and to merge the plurality of separate point-to-point LSPs into the point-to-multipoint LSP.

2. The method of claim **1** wherein the signaling of the point-to-multipoint LSP is initiated by an edge router attached to a source.

3. The method of claim **1** wherein each of the plurality of separate point-to-point LSPs is associated with an identifier of the point-to-multipoint LSP.

4. The method of claim **3** wherein the identifier of the point-to-multipoint LSP is provided by a session object included in each message exchanged between nodes identified in the plurality of separate point-to-point LSPs.

5. The method of claim **4** wherein the plurality of separate point-to-point LSPs share network resources.

6. A method in a network device comprising:

identifying a plurality of receivers requesting to receive data from a source in a session;

determining that the plurality of receivers do not belong to any existing point-to-multipoint label switch path (LSP);

computing a plurality of point-to-point LSPs for the plurality of receivers;

sending a plurality of PATH messages, each of the plurality of PATH messages pertaining to a corresponding one of the plurality of point-to-point LSPs, wherein each of the PATH messages does not include a representation of the topology of a point-to-multipoint LSP; and

merging the plurality of point-to-point LSPs into a point-to-multipoint LSP.

7. The method of claim **6** wherein point-to-point LSPs computed for the plurality of receivers are to share links where possible.

8. The method of claim **6** further comprising:

including an identifier of the point-to-multipoint LSP in each of the plurality of PATH messages.

9. The method of claim **8** further comprising:

receiving one or more RESV messages including the identifier of the point-to-multipoint LSP from one or more downstream nodes; and

creating a multicast label mapping for the point-to-multipoint LSP based on labels specified in the one or more RESV messages.

10. The method of claim **6** further comprising:

maintaining a path counter associated with the point-to-multipoint LSP, the path counter specifying a number of the plurality of point-to-point LSPs in the point-to-multipoint LSP.

11. The method of claim **6** further comprising:

storing the point-to-multipoint LSP in the network device as a tree data structure.

12. The method of claim **6** further comprising:

identifying a new receiver joining the session;

determining that the new receiver belongs to the point-to-multipoint LSP;

computing a point-to-point LSP for the new receiver;

sending a PATH message for the computed point-to-point LSP; and

adding the point-to-point LSP for the new receiver to the point-to-multipoint LSP.

13. The method of claim **6** further comprising:

determining that one of the plurality of receivers is to be removed from the session;

sending a PATH TEAR message to a corresponding downstream node; and

removing the plurality of point-to-point LSPs to the one of the plurality of receivers from the point-to-multipoint LSP.

14. The method of claim **13** further comprising:

determining that the point-to-multipoint LSP indicates that the corresponding downstream node is involved only in a route to the one of the plurality of receivers that is to be removed; and

updating a multicast label mapping for the point-to-multipoint LSP to remove a label associated with the corresponding downstream node.

15. A method in a network device comprising:

receiving a PATH message identifying a route from the network device to a receiver, wherein the PATH message does not include a representation of the topology of a point-to-multipoint label switched path (LSP);

determining that the received PATH message is associated with an existing partial point-to-multipoint label switch path (LSP);

receiving a RESV message matching the received PATH message, the received RESV message including a label; and

adding the label to a multicast label mapping associated with the existing partial point-to-multipoint LSP.

16. The method of claim **15** wherein each of the received PATH message and RESV message includes an identifier of a point-to-multipoint LSP to which the existing partial point-to-multipoint LSP belongs.

17. The method of claim **15** further comprising:

merging the route from the received PATH message with the existing partial point-to-multipoint LSP, the existing partial point-to-multipoint LSP being maintained by the network device.

18. The method of claim **15** wherein the existing partial point-to-multipoint LSP is represented as a tree.

19. The method of claim **16** further comprising:

sending a next PATH message to a downstream node, the next PATH message including the identifier of the point-to-multipoint LSP; and

incrementing a path counter maintained by the network device for the existing partial point-to-multipoint LSP, the path counter specifying a number of unicast paths in the existing partial point-to-multipoint LSP.

20. The method of claim **16** further comprising:

sending a next RESV message to an upstream node upon processing the received RESV message, the next RESV message including the identifier of the point-to-multipoint LSP.

21. The method of claim **15** further comprising:

determining that the received PATH message is not associated with any existing partial point-to-multipoint LSP;

creating a new partial point-to-multipoint LSP;

creating a path counter for the new partial point-to-multipoint LSP;

sending a next PATH message to a downstream node, the next PATH message including an identifier of a point-to-multipoint LSP to which the new partial point-to-multipoint LSP belongs;

receiving a RESV message matching the PATH message from the downstream node;

creating a multicast label mapping for the new partial point-to-multipoint LSP; and

sending a next RESV message to an upstream node, the next RESV message including the identifier of the point-to-multipoint LSP.

22. The method of claim **15** further comprising:

receiving, from an upstream node, a PATH TEAR message identifying a path to be removed, the PATH TEAR message including an identifier of a point-to-multipoint LSP to which the existing partial point-to-multipoint LSP belongs;

determining whether the new partial point-to-multipoint LSP indicates that the network device is involved only in a route to the receiver to be removed; and

sending a next PATH TEAR message to a corresponding downstream node.

23. The method of claim **22** wherein the determining whether the existing partial point-to-multipoint LSP indicates that the network device is involved only in a route to the receiver to be removed comprises:

determining whether the path counter is equal to one.

24. The method of claim **23** further comprising:

determining that the path counter is equal to one; and

deleting the existing partial point-to-multipoint LSP and the path counter and multicast label mapping associated with the existing partial point-to-multipoint LSP.

25. The method of claim **23** further comprising:

determining that the path counter is greater than one; and

removing the path identified in the PATH TEAR message from the existing partial point-to-multipoint LSP.

26. The method of claim **25** further comprising:

determining that the existing partial point-to-multipoint LSP indicates that the corresponding downstream node is involved only in a route to the receiver to be removed; and

removing a label associated with the corresponding downstream node from the multicast label mapping.

27. A system comprising:

an edge router to compute a plurality of point-to-point label switch paths (LSPs) for a plurality of receivers associated with a session, to send a plurality of PATH messages for the plurality of point-to-point LSPs, wherein each of the PATH messages does not include a representation of the topology of a point-to-multipoint LSP, and to merge the plurality of point-to-point LSPs into a point-to-multipoint label switch path (LSP); and

one or more core routers, coupled to the edge router, to receive the plurality of PATH messages, to receive a plurality of RESV messages matching corresponding PATH messages, and to create a multicast label mapping for the point-to-multipoint LSP using label information contained in the plurality of RESV messages.

28. The system of claim **27** wherein each of the plurality of point-to-point LSPs is associated with an identifier of the point-to-multipoint LSP.

29. The system of claim **28** wherein the identifier of the point-to-multipoint LSP is provided by a session object included in each message exchanged between the edge router and the one or more core routers.

30. The system of claim **29** wherein the plurality of point-to-point LSPs share network resources.

31. A network element comprising:

a control card to host a Resource Reservation Protocol (RSVP) module, the RSVP module to maintain one or more partial point-to-multipoint label switch paths (LSPs) established by merging unicast paths specified in a plurality of PATH messages received by the network element and to receive a plurality of RESV messages matching corresponding PATH messages, wherein each of the received PATH messages does not include a representation of the topology of a point-to-multipoint LSP; and

a plurality of line cards, coupled to the control card, to contain a plurality of forwarding information bases (FIBs),

wherein the plurality of FIBs is to store multicast mappings of labels specified in the plurality of RESV messages.

32. The network element of claim **31** wherein the RSVP module is to add a label to one of the multicast label mappings if an RESV message containing the label pertains to a partial point-to-multipoint LSP associated with said one of the multicast label mappings.

33. The network element of claim **31** wherein each of the received PATH messages and RESV messages includes an identifier of a point-to-multipoint LSP to which a corresponding partial point-to-multipoint LSP belongs.

34. A network element comprising:

a control card to include a Resource Reservation Protocol (RSVP) module, the RSVP module to establish a plurality of point-to-point label switch paths (LSPs) to reach a plurality of receivers participating in a session, to send a plurality of PATH messages for corresponding point-to-point LSPs, wherein each of the PATH messages does not include a representation of the topology of a point-to-multipoint LSP, and to merge the plurality of point-to-point LSPs into a point-to-multipoint LSP; and

a plurality of line cards, coupled to the control card, to contain a plurality of forwarding information bases (FIBs),

wherein the plurality of FIBs is to store muticast mappings of labels specified in a plurality of RESV messages received by the network element.

35. The network element of claim **34** wherein the plurality of point-to-point LSPs are to share links where possible.

36. The network element of claim **34** wherein the RSVP module is to include an identifier of the point-to-multipoint LSP in each of the plurality of PATH messages.

37. The network element of claim **34** further comprising a tree data structure to store the point-to-multipoint ISP.

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CERTIFICATE OF CORRECTION

PATENT NO. : 7,477,642 B2
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DATED : January 13, 2009
INVENTOR(S) : Aggarwal et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In column 5, at line 47, delete "ISPs" and insert --LSPs--.
In column 14, at line 58, delete "ISP." and insert --LSP.--.

Signed and Sealed this

Seventh Day of April, 2009

John Doll

JOHN DOLL
Acting Director of the United States Patent and Trademark Office