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(12) **United States Patent**
Moynihan et al.

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(45) **Date of Patent: Dec. 19, 2017**

(54) **SERVICE PREEMPTION SELECTION SYSTEMS AND METHODS IN NETWORKS**

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(73) Assignee: **Ciena Corporation**, Hanover, MD (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 288 days.

(21) Appl. No.: **14/875,760**

(22) Filed: **Oct. 6, 2015**

(65) **Prior Publication Data**

US 2017/0099354 A1 Apr. 6, 2017

(51) **Int. Cl.**
H04L 29/08 (2006.01)
H04L 12/701 (2013.01)

(52) **U.S. Cl.**
CPC ***H04L 67/141*** (2013.01); ***H04L 45/00*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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(Continued)

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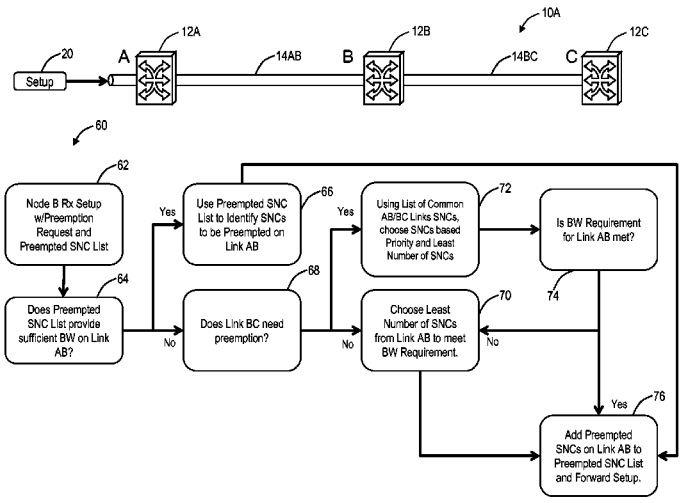
(57) **ABSTRACT**

Systems and methods for service preemption selection implemented by a node in a network include receiving, from an ingress link, a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request comprises a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link; selecting, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria; and forwarding the request on an egress link to an adjacent node with any updates based on the selecting.

18 Claims, 19 Drawing Sheets



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"Architecture for the automatically switched optical network," International Telecommunication Union, Feb. 2012, pp. 1-124.

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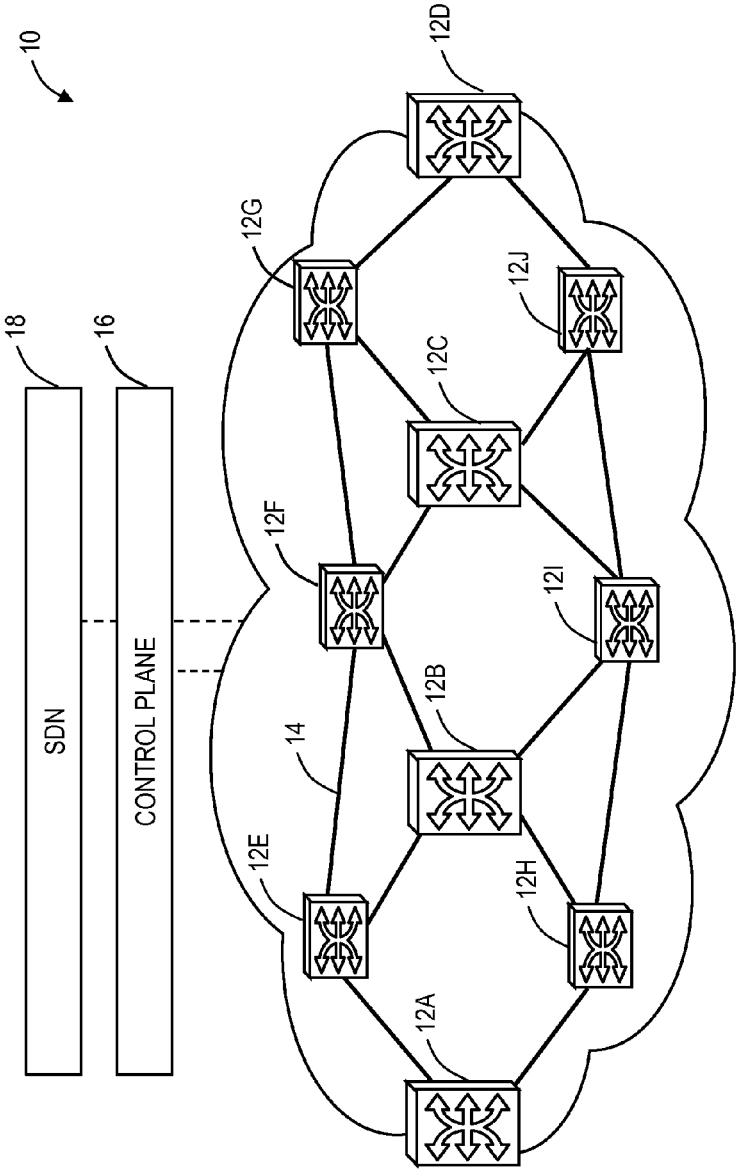

10
12D
12G
12J
12C
12F
12I
12B
14
12E
12H
12A
18
16
SDN
CONTROL PLANE

FIG. 1A

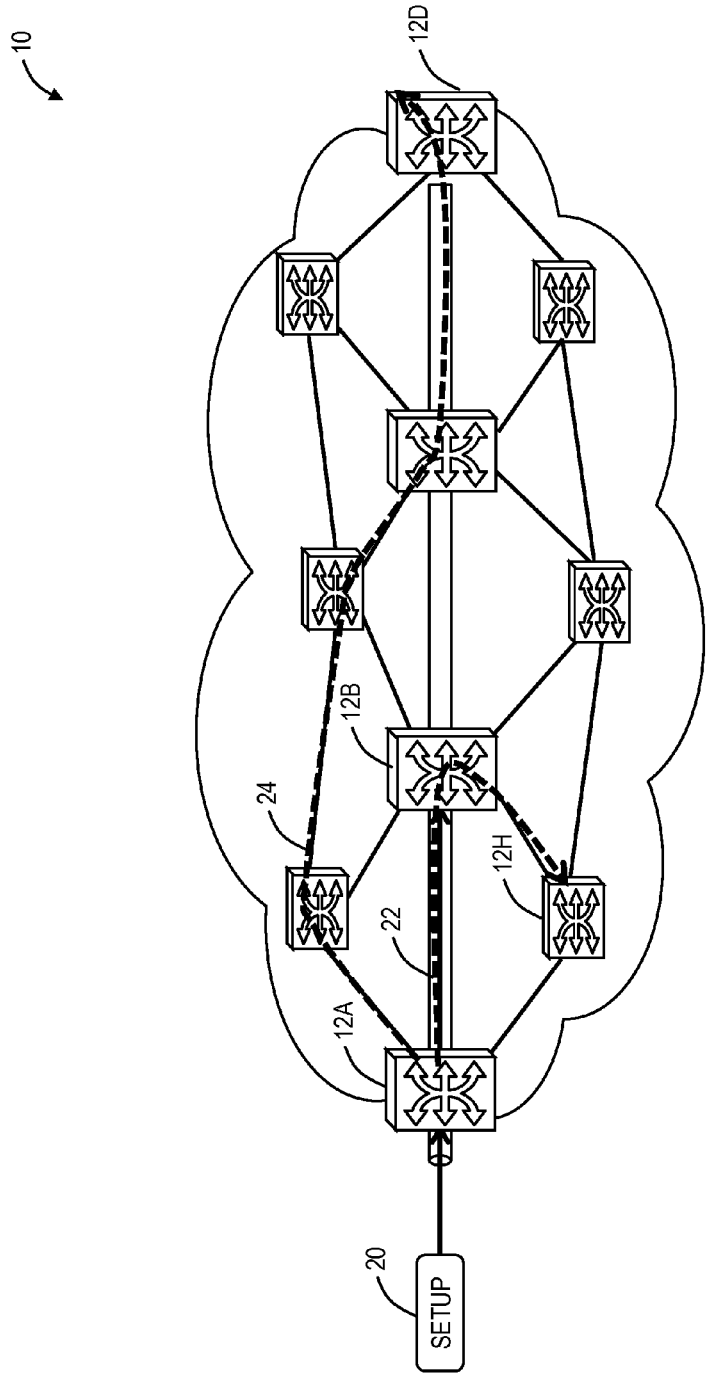


FIG. 1B

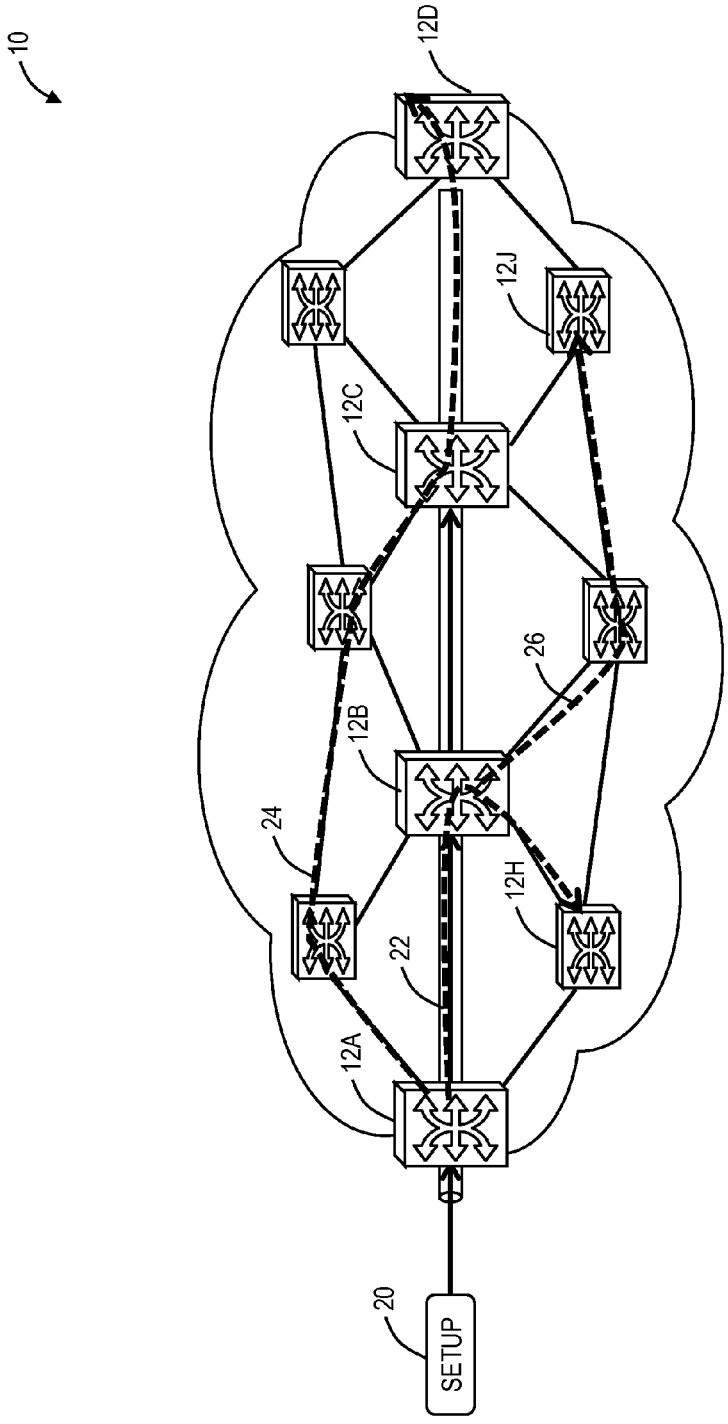


FIG. 1C

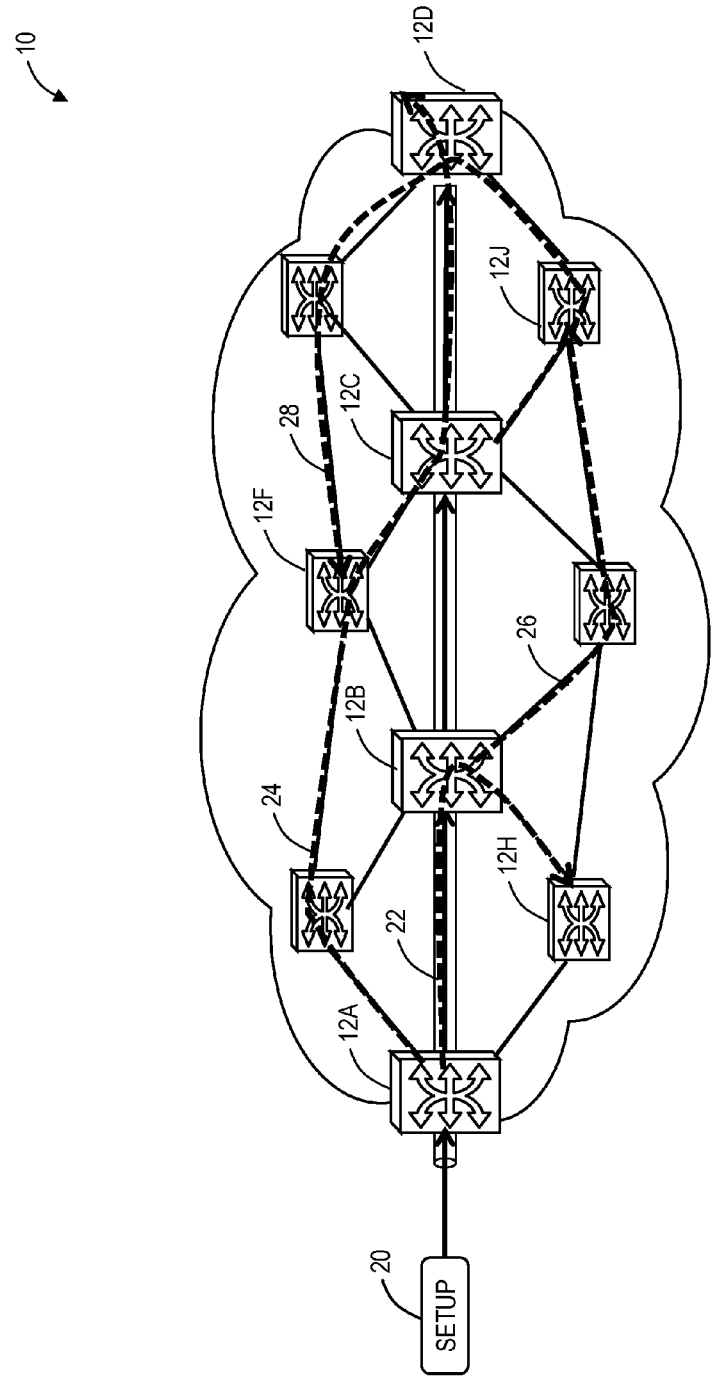


FIG. 1D

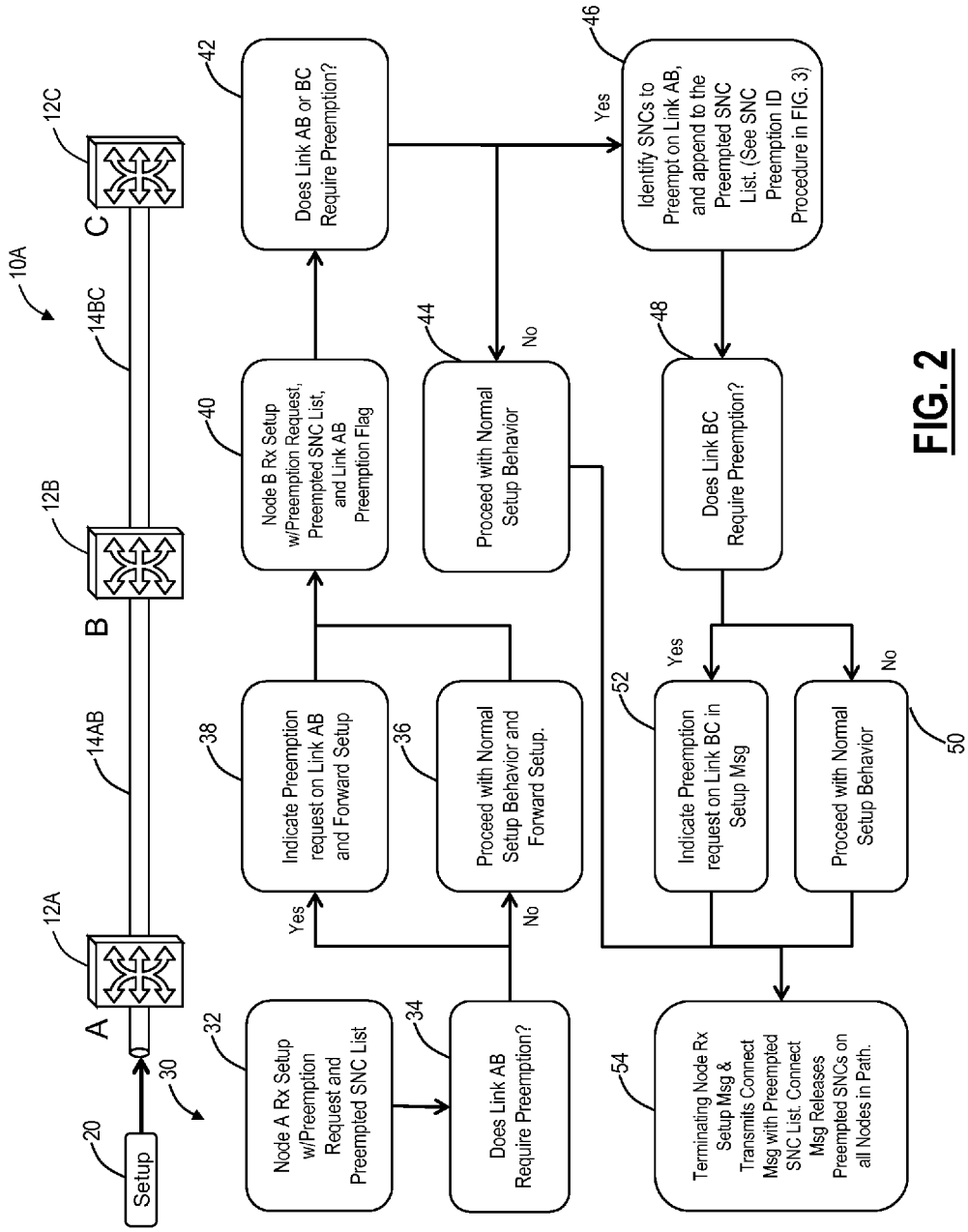

10A
A
B
C
12A
12B
12C
14AB
14BC
20
Setup
30
32
Node A Rx Setup w/Preemption Request and Preempted SNC List
34
Does Link AB Require Preemption?
Yes
No
36
Proceed with Normal Setup Behavior and Forward Setup.
38
Indicate Preemption request on Link AB and Forward Setup
40
Node B Rx Setup w/Preemption Request, Preempted SNC List, and Link AB Preemption Flag
42
Does Link AB or BC Require Preemption?
Yes
No
44
Proceed with Normal Setup Behavior
46
Identify SNCs to Preempt on Link AB, and append to the Preempted SNC List. (See SNC Preemption ID Procedure in FIG. 3)
48
Does Link BC Require Preemption?
Yes
No
50
Proceed with Normal Setup Behavior
52
Indicate Preemption request on Link BC in Setup Msg
54
Terminating Node Rx Setup Msg & Transmits Connect Msg with Preempted SNC List. Connect Msg Releases Preempted SNCs on all Nodes in Path.

FIG. 2

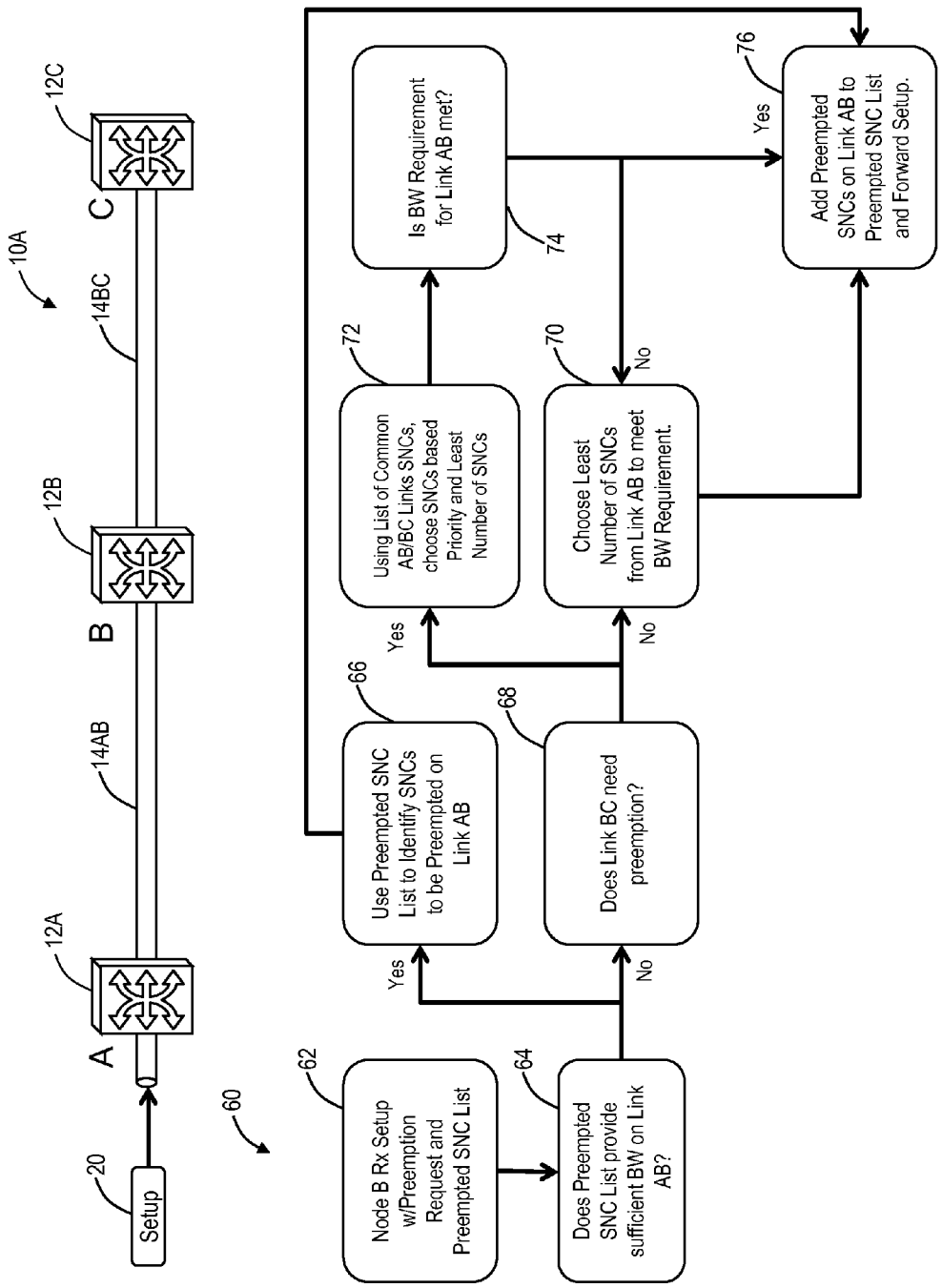
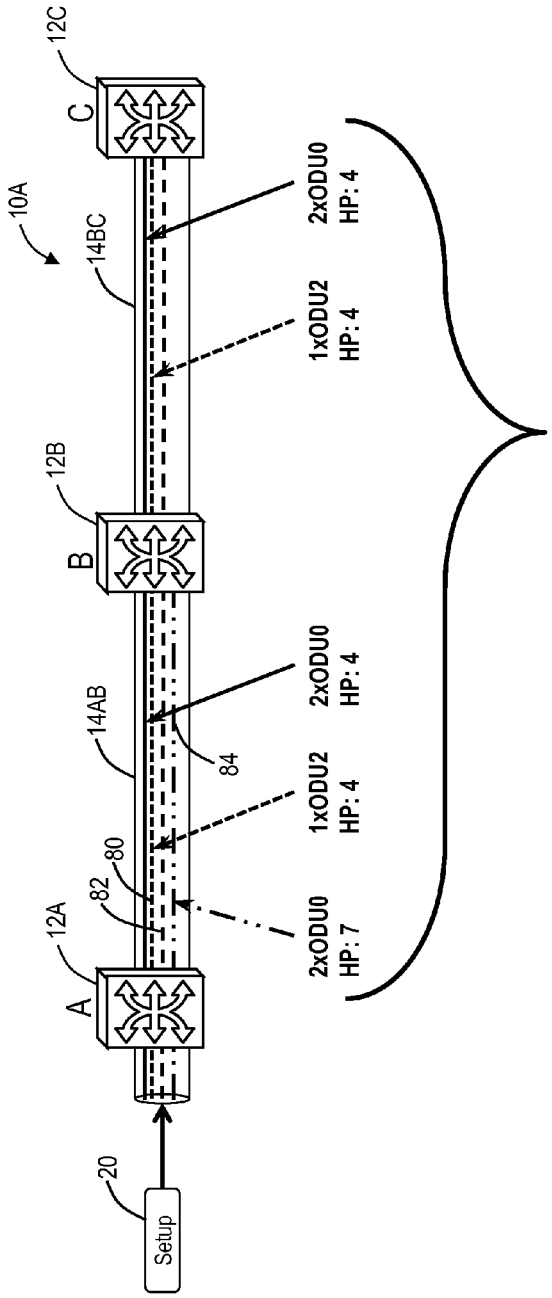

10A
12A
A
14AB
12B
B
14BC
12C
C
20
Setup
60
62
Node B Rx Setup w/Preemption Request and Preempted SNC List
64
Does Preempted SNC List provide sufficient BW on Link AB?
Yes
No
66
Use Preempted SNC List to Identify SNCs to be Preempted on Link AB
68
Does Link BC need preemption?
Yes
No
72
Using List of Common AB/BC Links SNCs, choose SNCs based Priority and Least Number of SNCs
70
Choose Least Number of SNCs from Link AB to meet BW Requirement.
No
74
Is BW Requirement for Link AB met?
Yes
76
Add Preempted SNCs on Link AB to Preempted SNC List and Forward Setup.

FIG. 3



SNCs Ordered by:
1. Holding Priority (HP)
2. SNC Size
3. SNC Rate

Link AB SNCs	
HP	SNC
7	2xODU0 Blue
4	2xODU0 Red
4	1xODU2 Green

Link BC SNCs	
HP	SNC
4	2xODU0 Red
4	1xODU2 Green

FIG. 4

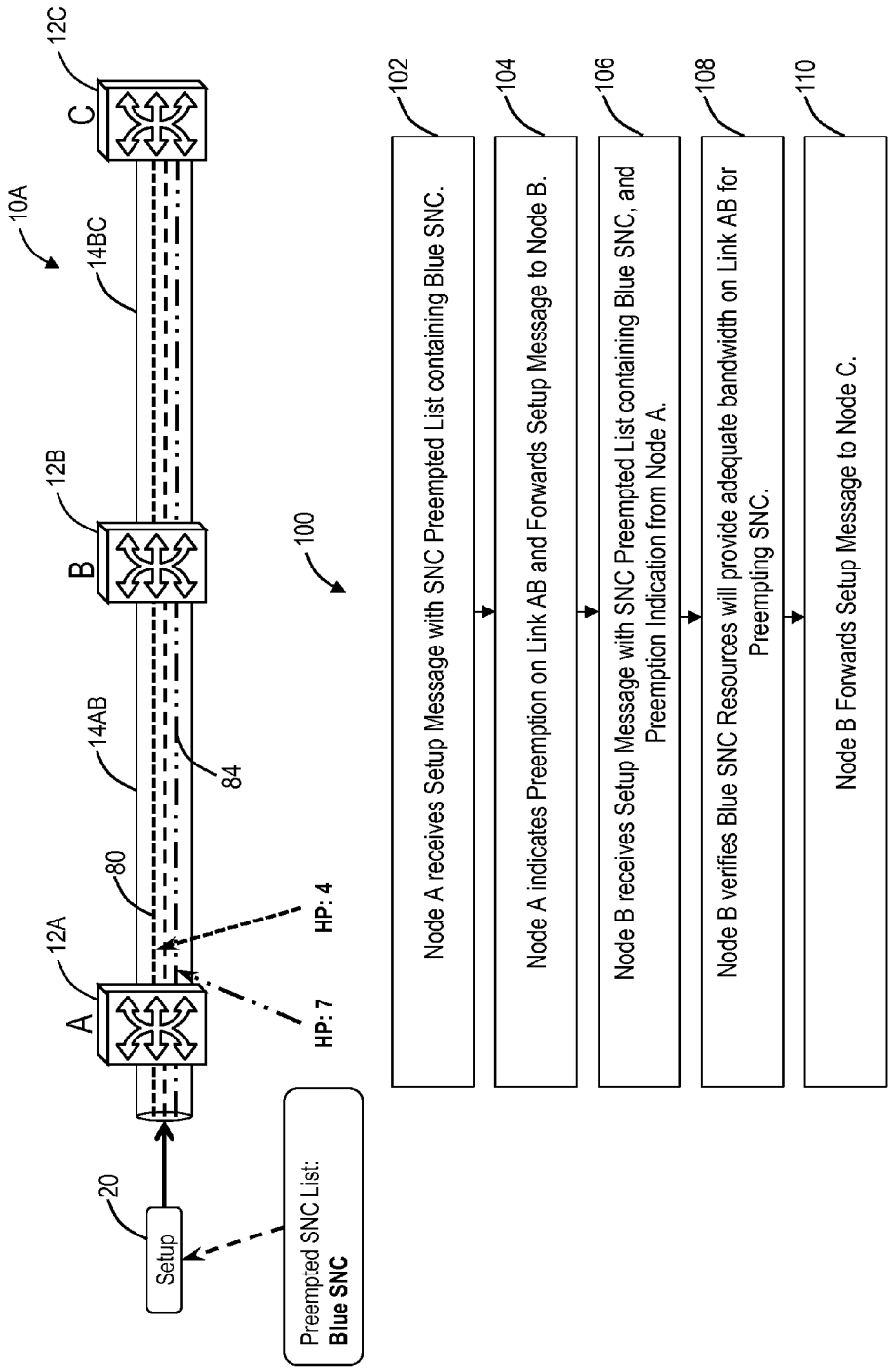

12C
C
10A
14BC
12B
B
100
14AB
84
80
12A
A
HP: 4
HP: 7
20
Setup
Preempted SNC List:
Blue SNC
102
Node A receives Setup Message with SNC Preempted List containing Blue SNC.
104
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
106
Node B receives Setup Message with SNC Preempted List containing Blue SNC, and Preemption Indication from Node A.
108
Node B verifies Blue SNC Resources will provide adequate bandwidth on Link AB for Preempting SNC.
110
Node B Forwards Setup Message to Node C.

FIG. 5

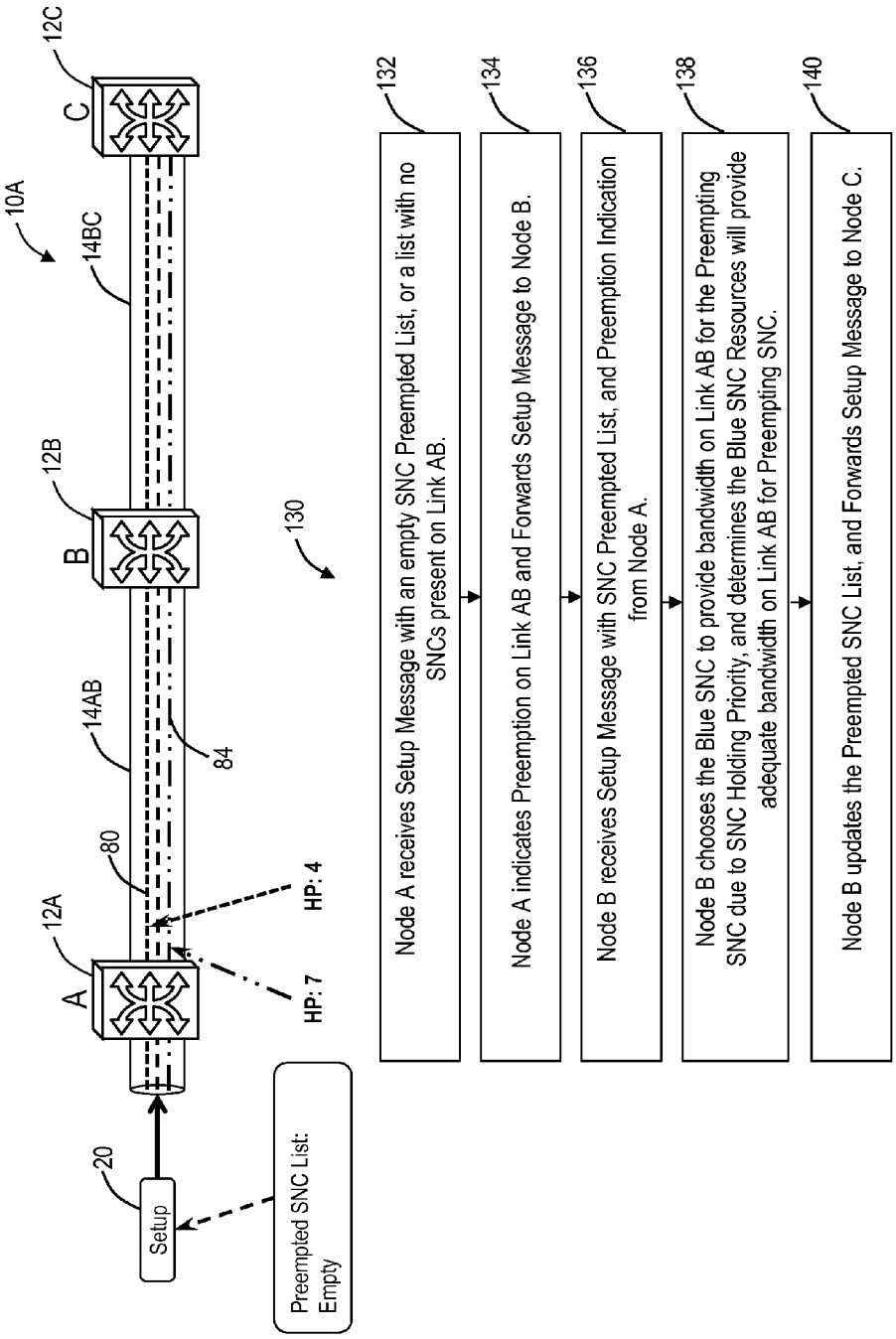
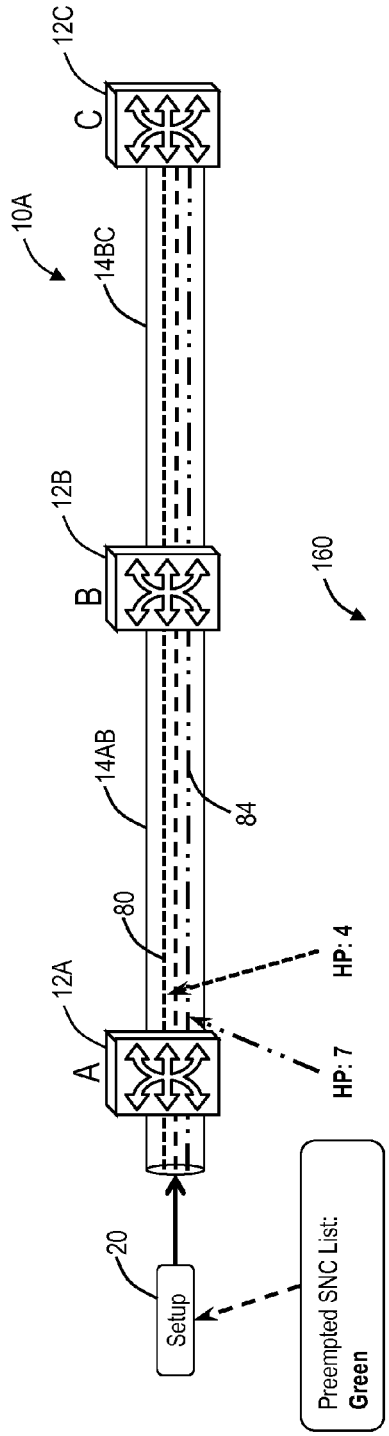

10A
12A
A
12B
B
12C
C
14AB
14BC
80
84
130
HP: 4
HP: 7
20
Setup
Preempted SNC List: Empty
132
Node A receives Setup Message with an empty SNC Preempted List, or a list with no SNCs present on Link AB.
134
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
136
Node B receives Setup Message with SNC Preempted List, and Preemption Indication from Node A.
138
Node B chooses the Blue SNC to provide bandwidth on Link AB for the Preempting SNC due to SNC Holding Priority, and determines the Blue SNC Resources will provide adequate bandwidth on Link AB for Preempting SNC.
140
Node B updates the Preempted SNC List, and Forwards Setup Message to Node C.

FIG. 6


10A
12C
C
14BC
12B
B
160
14AB
84
80
12A
A
HP: 4
HP: 7
20
Setup
Preempted SNC List:
Green

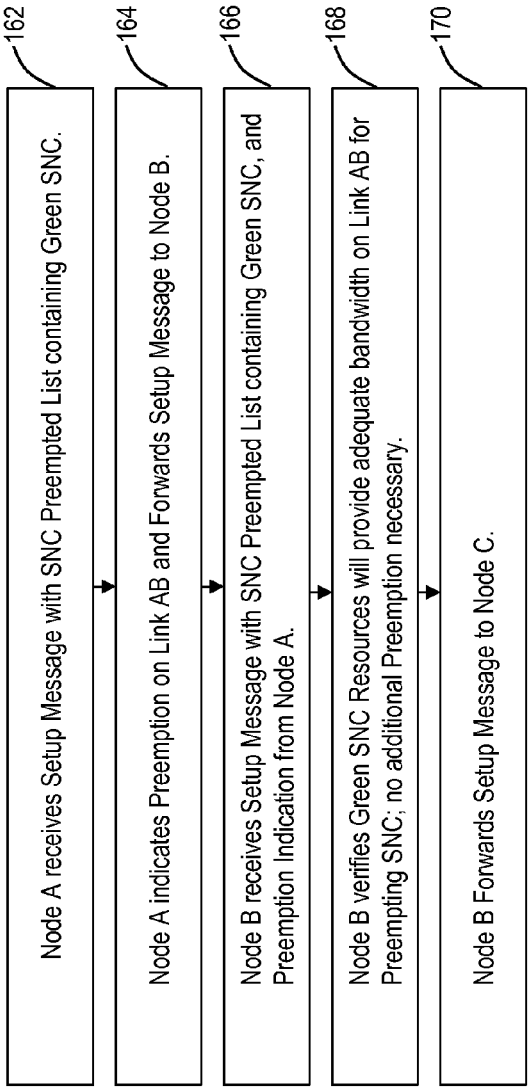
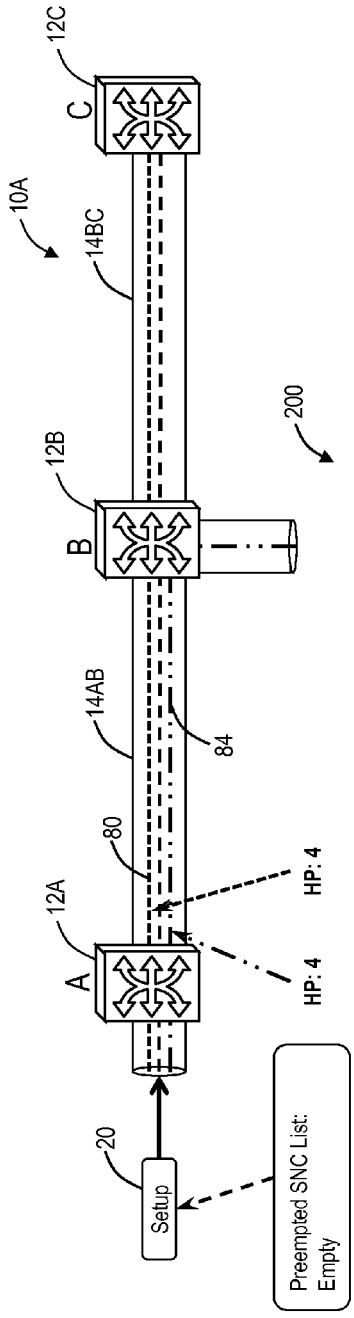

162
Node A receives Setup Message with SNC Preempted List containing Green SNC.
164
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
166
Node B receives Setup Message with SNC Preempted List containing Green SNC, and Preemption Indication from Node A.
168
Node B verifies Green SNC Resources will provide adequate bandwidth on Link AB for Preempting SNC; no additional Preemption necessary.
170
Node B Forwards Setup Message to Node C.

FIG. 7


10A
12A
A
12B
B
12C
C
14AB
14BC
80
84
200
HP: 4
HP: 4
20
Setup
Preempted SNC List: Empty

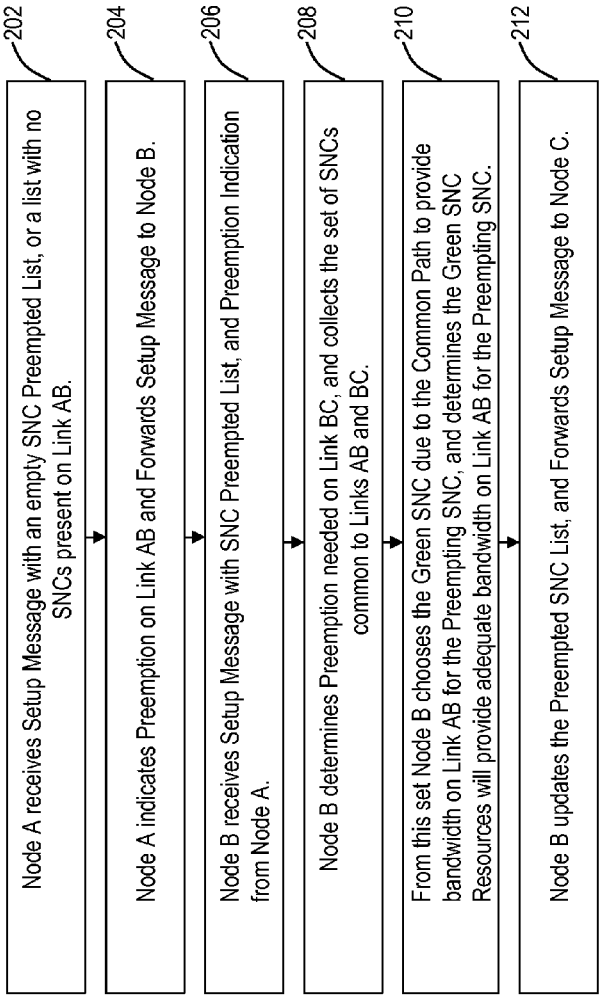

202
Node A receives Setup Message with an empty SNC Preempted List, or a list with no SNCs present on Link AB.
204
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
206
Node B receives Setup Message with SNC Preempted List, and Preemption Indication from Node A.
208
Node B determines Preemption needed on Link BC, and collects the set of SNCs common to Links AB and BC.
210
From this set Node B chooses the Green SNC due to the Common Path to provide bandwidth on Link AB for the Preempting SNC, and determines the Green SNC Resources will provide adequate bandwidth on Link AB for the Preempting SNC.
212
Node B updates the Preempted SNC List, and Forwards Setup Message to Node C.

FIG. 8

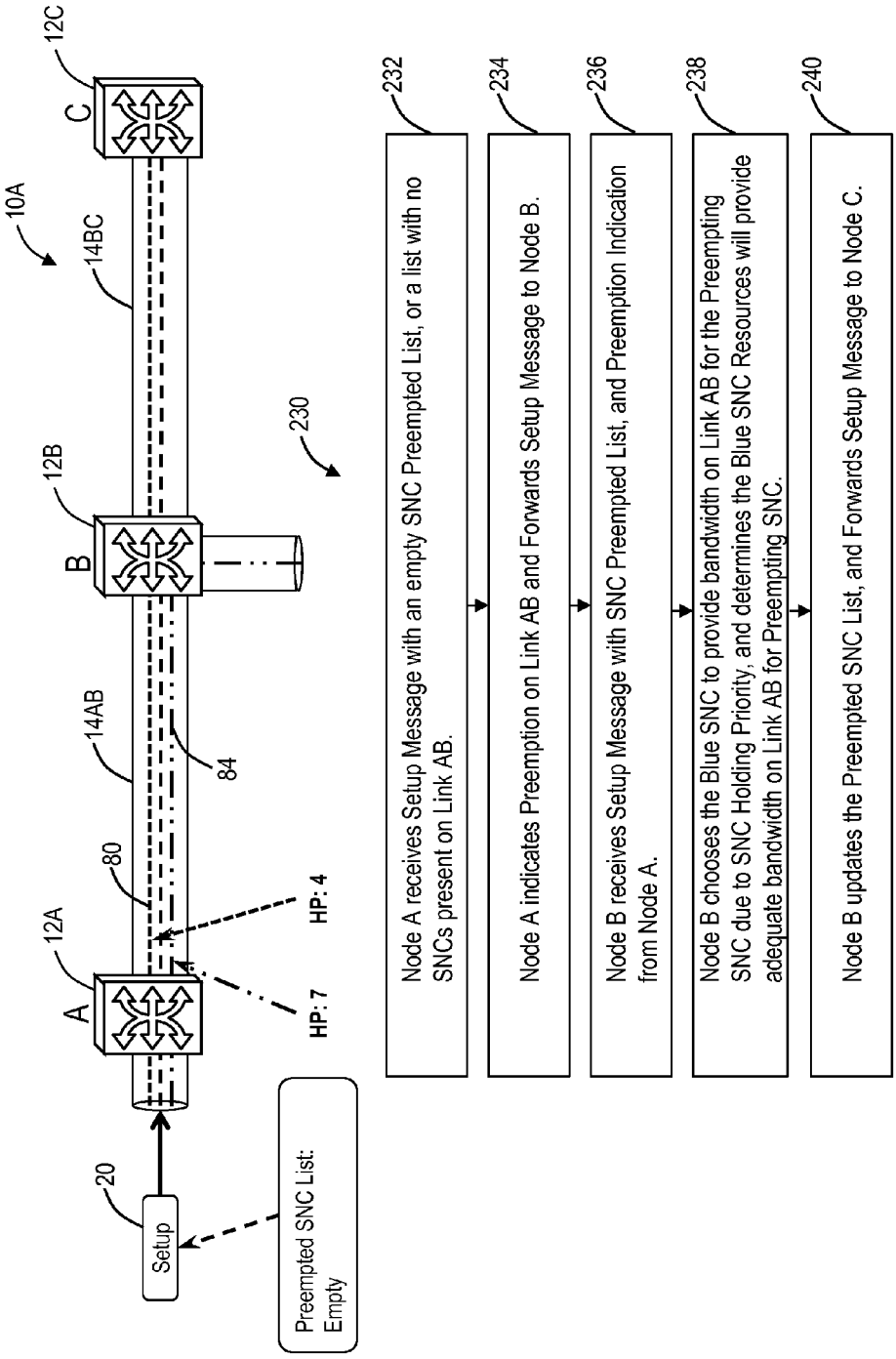
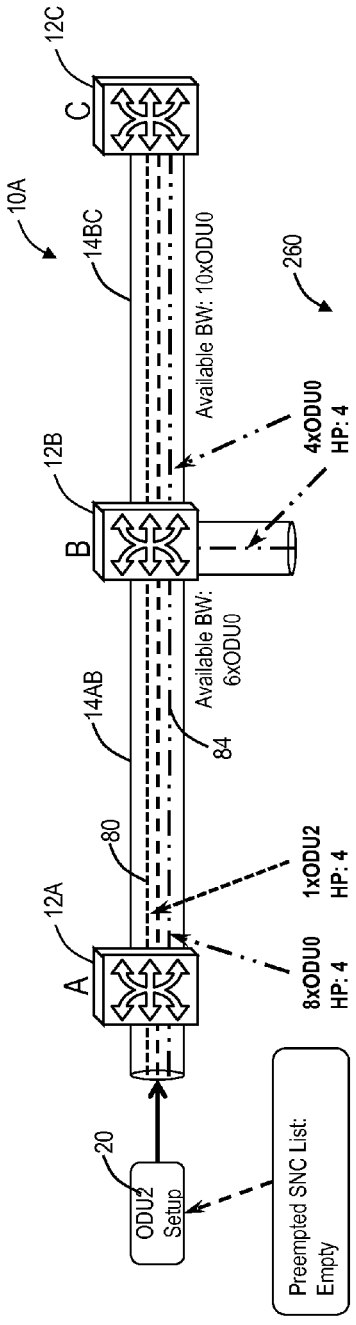

10A
12A
12B
12C
A
B
C
14AB
14BC
80
84
230
HP: 7
HP: 4
20
Setup
Preempted SNC List: Empty
232
Node A receives Setup Message with an empty SNC Preempted List, or a list with no SNCs present on Link AB.
234
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
236
Node B receives Setup Message with SNC Preempted List, and Preemption Indication from Node A.
238
Node B chooses the Blue SNC to provide bandwidth on Link AB for the Preempting SNC due to SNC Holding Priority, and determines the Blue SNC Resources will provide adequate bandwidth on Link AB for Preempting SNC.
240
Node B updates the Preempted SNC List, and Forwards Setup Message to Node C.

FIG. 9


10A
12A
A
12B
B
12C
C
14AB
14BC
80
84
20
ODU2 Setup
Preempted SNC List: Empty
8xODU0 HP: 4
1xODU2 HP: 4
4xODU0 HP: 4
260
Available BW: 6xODU0
Available BW: 10xODU0

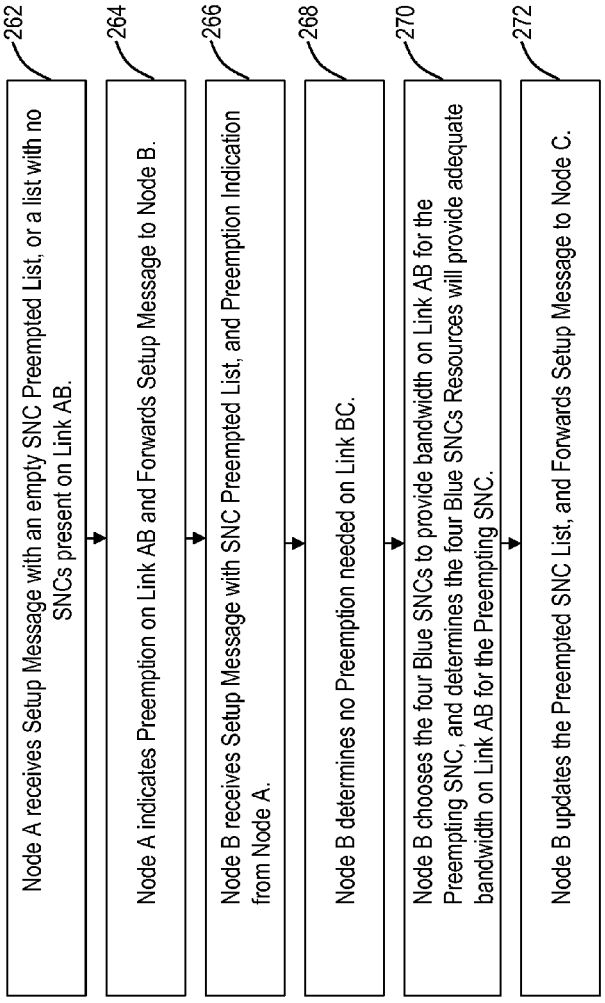

262
Node A receives Setup Message with an empty SNC Preempted List, or a list with no SNCs present on Link AB.
264
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
266
Node B receives Setup Message with SNC Preempted List, and Preemption Indication from Node A.
268
Node B determines no Preemption needed on Link BC.
270
Node B chooses the four Blue SNCs to provide bandwidth on Link AB for the Preempting SNC, and determines the four Blue SNCs Resources will provide adequate bandwidth on Link AB for the Preempting SNC.
272
Node B updates the Preempted SNC List, and Forwards Setup Message to Node C.

FIG. 10

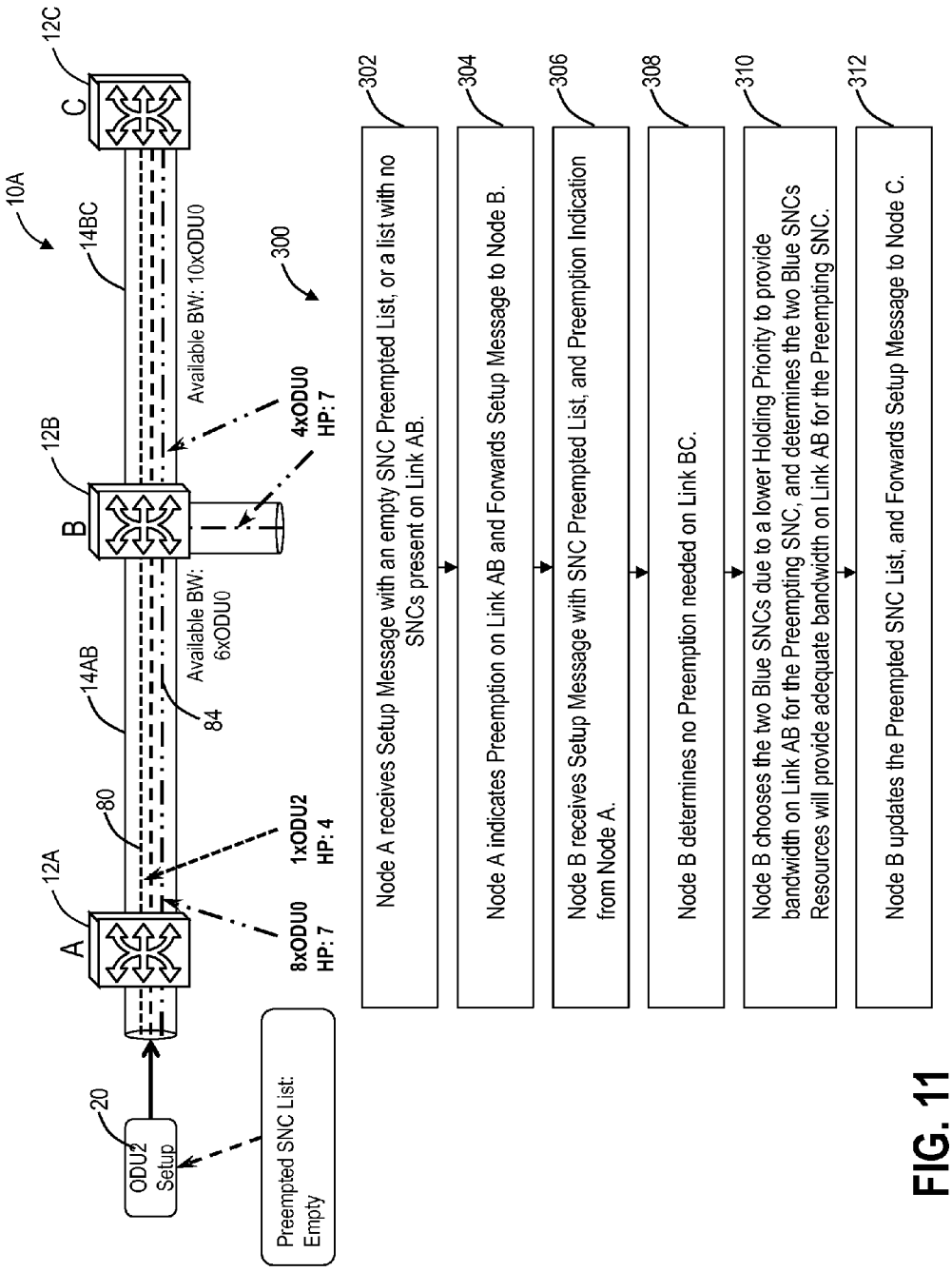
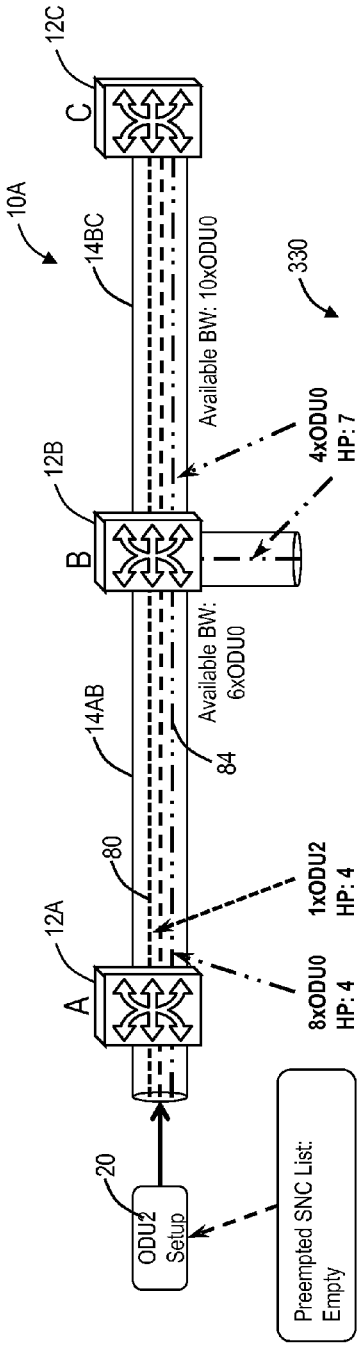

10A
12A
12B
12C
A
B
C
14AB
14BC
80
84
300
20
ODU2 Setup
Preempted SNC List: Empty
8xODU0 HP: 7
1xODU2 HP: 4
Available BW: 6xODU0
Available BW: 10xODU0
4xODU0 HP: 7
302
Node A receives Setup Message with an empty SNC Preempted List, or a list with no SNCs present on Link AB.
304
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
306
Node B receives Setup Message with SNC Preempted List, and Preemption Indication from Node A.
308
Node B determines no Preemption needed on Link BC.
310
Node B chooses the two Blue SNCs due to a lower Holding Priority to provide bandwidth on Link AB for the Preempting SNC, and determines the two Blue SNCs Resources will provide adequate bandwidth on Link AB for the Preempting SNC.
312
Node B updates the Preempted SNC List, and Forwards Setup Message to Node C.

FIG. 11


10A
12A
A
12B
B
12C
C
14AB
14BC
80
84
20
ODU2
Setup
Preempted SNC List:
Empty
8xODU0
HP: 4
1xODU2
HP: 4
Available BW:
6xODU0
Available BW: 10xODU0
4xODU0
HP: 7
330

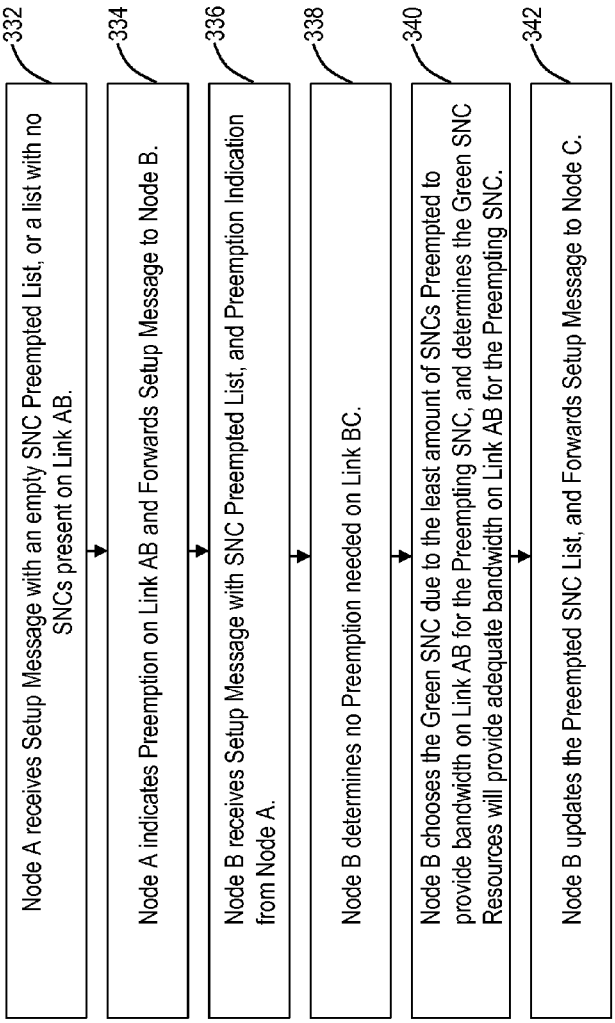

332
Node A receives Setup Message with an empty SNC Preempted List, or a list with no SNCs present on Link AB.
334
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
336
Node B receives Setup Message with SNC Preempted List, and Preemption Indication from Node A.
338
Node B determines no Preemption needed on Link BC.
340
Node B chooses the Green SNC due to the least amount of SNCs Preempted to provide bandwidth on Link AB for the Preempting SNC, and determines the Green SNC Resources will provide adequate bandwidth on Link AB for the Preempting SNC.
342
Node B updates the Preempted SNC List, and Forwards Setup Message to Node C.

FIG. 12

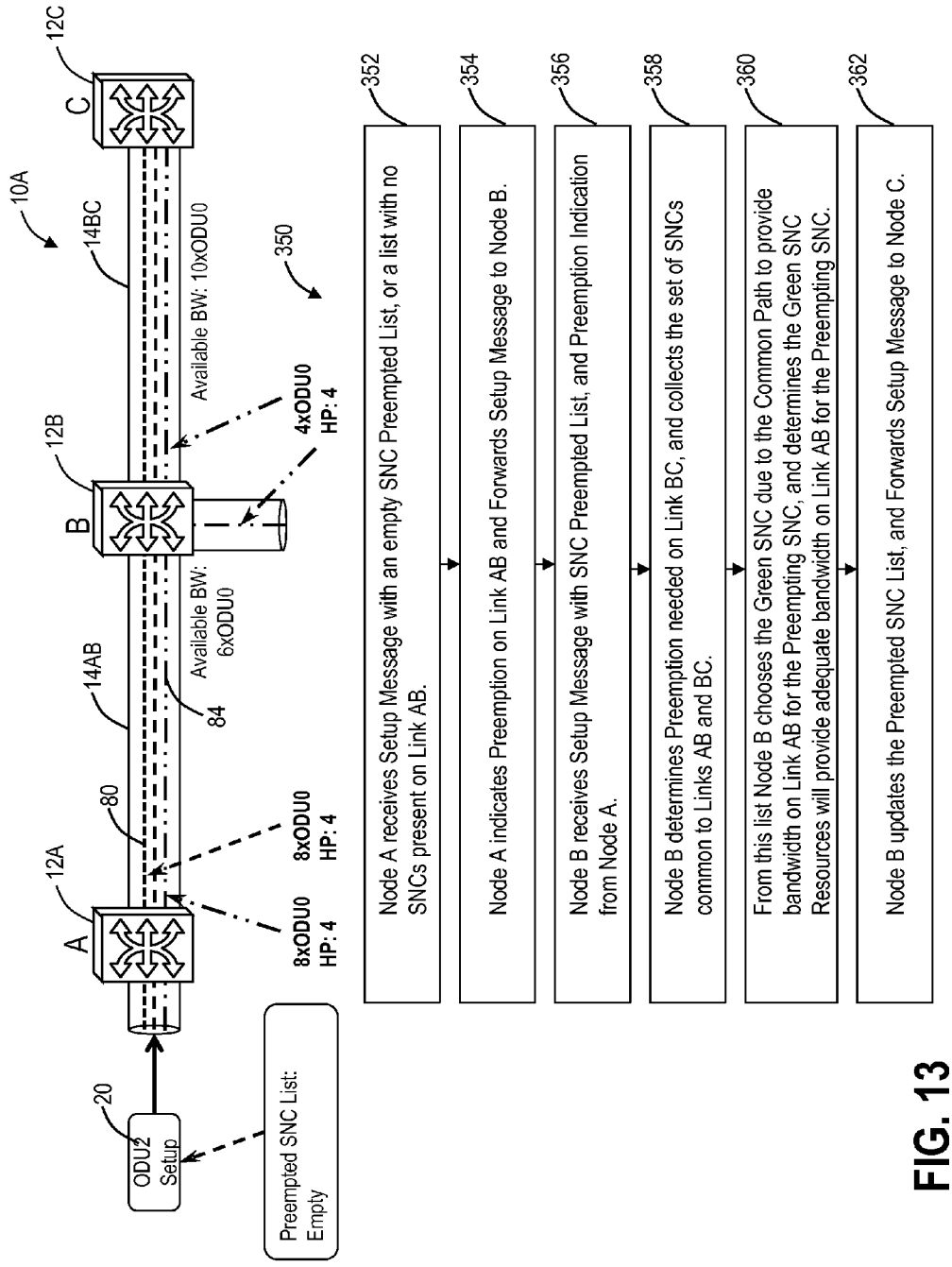

10A
12A
12B
12C
A
B
C
14AB
14BC
80
84
20
ODU2 Setup
Preempted SNC List: Empty
8xODU0 HP: 4
8xODU0 HP: 4
8xODU0 HP: 4
4xODU0 HP: 4
Available BW: 6xODU0
Available BW: 10xODU0
350
352
Node A receives Setup Message with an empty SNC Preempted List, or a list with no SNCs present on Link AB.
354
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
356
Node B receives Setup Message with SNC Preempted List, and Preemption Indication from Node A.
358
Node B determines Preemption needed on Link BC, and collects the set of SNCs common to Links AB and BC.
360
From this list Node B chooses the Green SNC due to the Common Path to provide bandwidth on Link AB for the Preempting SNC, and determines the Green SNC Resources will provide adequate bandwidth on Link AB for the Preempting SNC.
362
Node B updates the Preempted SNC List, and Forwards Setup Message to Node C.

FIG. 13

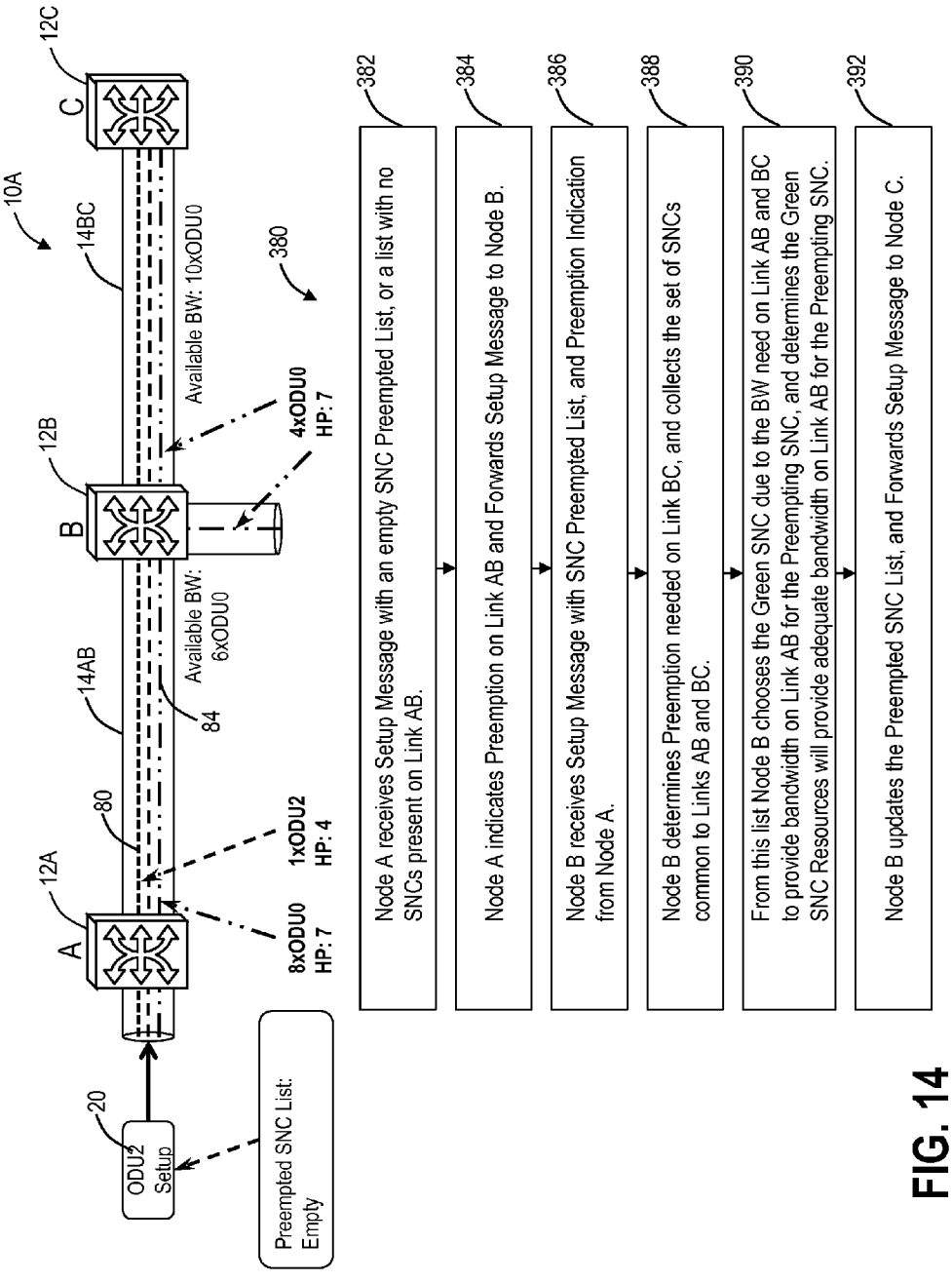

10A
12A
12B
12C
A
B
C
14AB
14BC
80
84
20
ODU2 Setup
Preempted SNC List: Empty
8xODU0 HP: 7
1xODU2 HP: 4
Available BW: 6xODU0
Available BW: 10xODU0
4xODU0 HP: 7
380
382
Node A receives Setup Message with an empty SNC Preempted List, or a list with no SNCs present on Link AB.
384
Node A indicates Preemption on Link AB and Forwards Setup Message to Node B.
386
Node B receives Setup Message with SNC Preempted List, and Preemption Indication from Node A.
388
Node B determines Preemption needed on Link BC, and collects the set of SNCs common to Links AB and BC.
390
From this list Node B chooses the Green SNC due to the BW need on Link AB and BC to provide bandwidth on Link AB for the Preempting SNC, and determines the Green SNC Resources will provide adequate bandwidth on Link AB for the Preempting SNC.
392
Node B updates the Preempted SNC List, and Forwards Setup Message to Node C.

FIG. 14

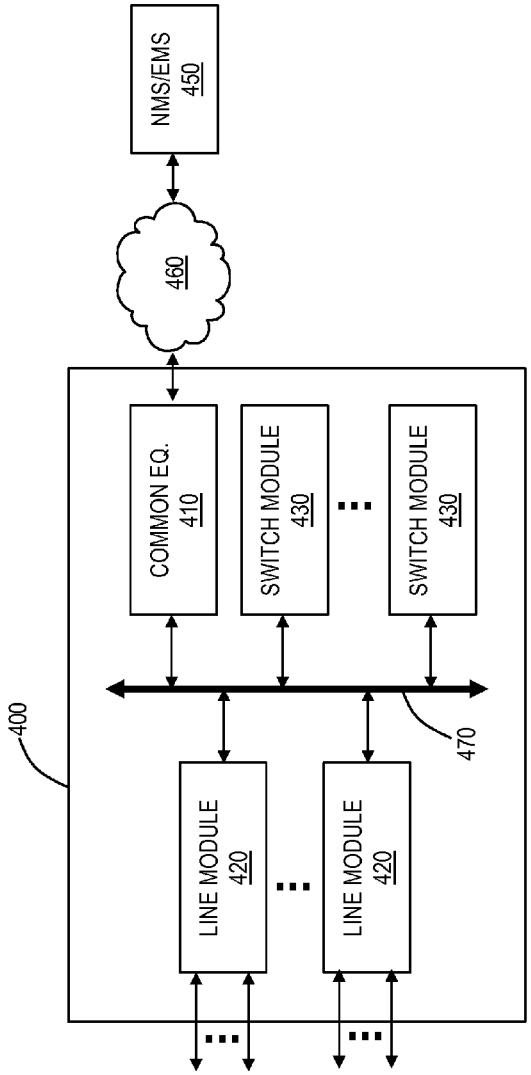

NMS/EMS
450
460
400
COMMON EQ.
410
SWITCH MODULE
430
SWITCH MODULE
430
470
LINE MODULE
420
LINE MODULE
420

FIG. 15

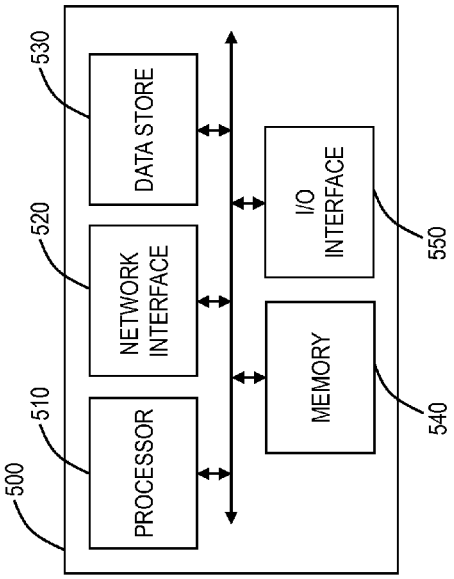

500
510
PROCESSOR
520
NETWORK INTERFACE
530
DATA STORE
MEMORY
540
I/O INTERFACE
550

FIG. 16

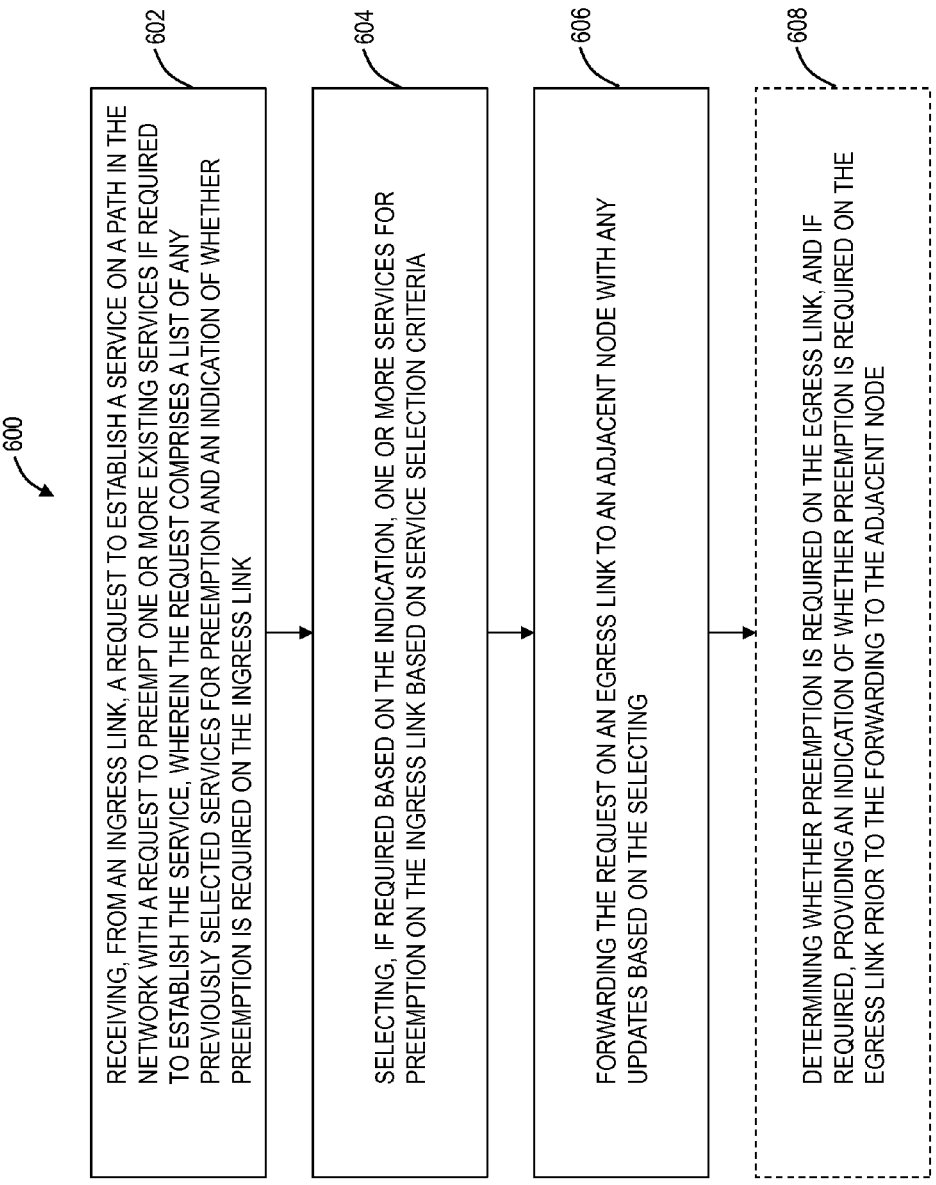

600
602
RECEIVING, FROM AN INGRESS LINK, A REQUEST TO ESTABLISH A SERVICE ON A PATH IN THE NETWORK WITH A REQUEST TO PREEMPT ONE OR MORE EXISTING SERVICES IF REQUIRED TO ESTABLISH THE SERVICE, WHEREIN THE REQUEST COMPRISES A LIST OF ANY PREVIOUSLY SELECTED SERVICES FOR PREEMPTION AND AN INDICATION OF WHETHER PREEMPTION IS REQUIRED ON THE INGRESS LINK
604
SELECTING, IF REQUIRED BASED ON THE INDICATION, ONE OR MORE SERVICES FOR PREEMPTION ON THE INGRESS LINK BASED ON SERVICE SELECTION CRITERIA
606
FORWARDING THE REQUEST ON AN EGRESS LINK TO AN ADJACENT NODE WITH ANY UPDATES BASED ON THE SELECTING
608
DETERMINING WHETHER PREEMPTION IS REQUIRED ON THE EGRESS LINK, AND IF REQUIRED, PROVIDING AN INDICATION OF WHETHER PREEMPTION IS REQUIRED ON THE EGRESS LINK PRIOR TO THE FORWARDING TO THE ADJACENT NODE

FIG. 17

SERVICE PREEMPTION SELECTION SYSTEMS AND METHODS IN NETWORKS

FIELD OF THE DISCLOSURE

The present disclosure generally relates to networking systems and methods. More particularly, the present disclosure relates to service preemption selection systems and methods in networks.

BACKGROUND OF THE DISCLOSURE

Optical networks and the like (e.g., Dense Wave Division Multiplexing (DWDM), Synchronous Optical Network (SONET), Synchronous Digital Hierarchy (SDH), Optical Transport Network (OTN), Ethernet, and the like) at various layers are deploying control plane systems and methods. Control planes provide an automatic allocation of network resources in an end-to-end manner. Exemplary control planes may include Automatically Switched Optical Network (ASON) as defined in ITU-T G.8080/Y.1304, Architecture for the automatically switched optical network (ASON) (02/2005), the contents of which are herein incorporated by reference; Generalized Multi-Protocol Label Switching (GMPLS) Architecture as defined in IETF Request for Comments (RFC): 3945 (10/2004) and the like, the contents of which are herein incorporated by reference; Optical Signaling and Routing Protocol (OSRP) from Ciena Corporation which is an optical signaling and routing protocol similar to Private Network-to-Network Interface (PNNI) and Multi-Protocol Label Switching (MPLS); or any other type control plane for controlling network elements at multiple layers, and establishing connections among nodes. Control planes are configured to establish end-to-end signaled connections such as Subnetwork Connections (SNCs) in ASON or OSRP and Label Switched Paths (LSPs) in GMPLS and MPLS. Note, as described herein, SNCs and LSPs can generally be referred to as services in the control plane. Also, note the aforementioned control planes are circuit-based control planes, e.g., operating at Layer 1 (Time Division Multiplexing (TDM)) and/or Layer 0 (wavelengths). Control planes use the available paths to route the services and program the underlying hardware accordingly.

Preemption is a process in a network where existing services are dropped or rerouted due to a lack of bandwidth for higher priority services. For example, preemption can occur when there is a fault, and higher priority services need to restore on a link, but the link has insufficient bandwidth. The preempted services can also attempt to restore. Thus, the preemption of one or more established SNCs or other services by another SNC in a control plane network causes increased instabilities as the preempted SNCs attempt to restore. Thus, it would be advantageous to limit the number of services affected by preemption. However, in a distributed control plane with a limited network view, such as GMPLS or ASON, network elements do not have visibility of all service paths in the network. While the originating (or source) network element can choose the lowest cost path for the service based on the knowledge of available bandwidth at a particular priority level on individual links, it does not have knowledge of the other services on those links; only the intermediate network elements know this information (intermediate network elements can also be referred to as transit network elements). Therefore, the originating network element cannot choose which services are preempted on individual links across the network.

Generally, the preemption process includes a SETUP message (in ASON, OSRP, etc.) or some other type of message, notification, etc. transmitted along the path of the service. The intermediate network elements choose one or more services on the link to preempt based on priority, rate, etc., but all based on the local knowledge of the services on the link. Service paths are not taken into account since this information is not available at the originating network element or locally on the intermediate network elements. Thus, if SNC A is preempted on the first link, SNC B may be preempted on the second link causing multiple SNCs to mesh restore. Whereas a more intelligent design maybe only SNC A released on both links. The preempting SETUP Message must be sent without the knowledge of how much instability the action will cause. The decision of which services to preempt must be made by the intermediate network elements. These intermediate network elements have no knowledge of service paths other than the two links in the preempting service's path connected to that network element. Similar to the originating network element, the decision of which services to preempt on these links may not be optimal due to this lack of network visibility.

Software Defined Networking (SDN) utilizes a centralized controller and may have a better view of the network allowing for more informed decisions about the preemption path and services to preempt. However, the level of knowledge may not be complete or may be inaccurate; especially in the case of a hybrid control plane which includes a distributed control plane overseen by a centralized controller where the network elements are given some level of control when restoring services. In the hybrid case, this occurs in two possible scenarios. First, if the network does not advertise services on individual lines within an aggregated link, the centralized controller cannot efficiently choose services to preempt on individual links. This is because it cannot know which lines within the link the preempting service will be assigned. This decision is made locally by the network elements. Second, if the network elements are allowed to perform route calculation during mesh restoration, the centralized controller may not immediately know where the services are routed in the network. This can occur if one or more originating network elements exhaust all protect routes provided by the centralized controller for one or more SNC's.

In circuit-based control planes, SDN, and hybrid control plane networks, it would be advantageous for optimized service preemption selection systems and methods that minimize the impact to other services during preemption.

BRIEF SUMMARY OF THE DISCLOSURE

In an exemplary embodiment, a method of service preemption selection implemented by a node in a network includes receiving, from an ingress link, a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request includes a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link; selecting, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria; and forwarding the request on an egress link to an adjacent node with any updates based on the selecting. The selecting can be performed with the list including a backward view of the previously selected services for preemption and a limited forward view where the node performs the selecting based in part on the egress link. The method can further include

determining whether preemption is required on the egress link, and if required, providing an indication of whether preemption is required on the egress link during the forwarding to the adjacent node. The updates can include addition of the one or more services for preemption in the request. The service selection criteria can be a hierarchical approach for determining the one or more services for preemption based first on the list, second on a common path between the ingress link and the egress link, and third based on characteristics of the one or more services for preemption. The network can utilize one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller. The network can utilize a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller, and wherein the SDN controller provides suggestions for the selecting in the request. The node and each intermediate node in the network for the service can be configured to perform the selecting, and wherein the list is utilized to select previously selected services to minimize disruption in the network.

In another exemplary embodiment, a node in a network configured to perform service preemption selection includes a first port coupled to an ingress link, wherein the first port is configured to receive a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request includes a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link; a controller configured to select, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria; and a second port configured to forward the request on an egress link to an adjacent node with any updates based on the one or more services for preemption. The one or more services for preemption can be selected with the list including a backward view of the previously selected services for preemption and a limited forward view where the node performs the selecting based in part on the egress link. The controller can be further configured to determine whether preemption is required on the egress link, and if required, providing an indication of whether preemption is required on the egress link when the second port forwards the request on the egress link. The updates can include addition of the one or more services for preemption in the request. The service selection criteria can be a hierarchical approach for determining the one or more services for preemption based first on the list, second on a common path between the ingress link and the egress link, and third based on characteristics of the one or more services for preemption. The network can utilize one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller. The network can utilize a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller, and wherein the SDN controller provides suggestions for how the controller selects the one or more services for preemption. The node and each intermediate node in the network for the service can be configured to perform the preemption, and wherein the list is utilized to select previously selected services to minimize disruption in the network.

In a further exemplary embodiment, a network configured to perform service preemption selection by one or more nodes includes a plurality of nodes interconnected to one another by a plurality of links; wherein an intermediate node is configured to receive, from an ingress link, a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request includes a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link, select, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria, and forward the request on an egress link to an adjacent node with any updates based on the selecting. The one or more services for preemption can be selected with the list including a backward view of the previously selected services for preemption and a limited forward view where the intermediate node performs the selecting based in part on the egress link. The intermediate node can be configured to determine whether preemption is required on the egress link, and if required, provide an indication of whether preemption is required on the egress link when forwarding to the adjacent node and an indication of any service preempted on the ingress link. The network can utilize one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is illustrated and described herein with reference to the various drawings, in which like reference numbers are used to denote like system components/method steps, as appropriate, and in which:

FIG. **1**A is a network diagram of an exemplary network with various interconnected nodes;

FIGS. **1**B-**1**D are network diagrams of the exemplary network of FIG. **1**A illustrating an exemplary preemption operation;

FIG. **2** is a flowchart of a service preemption identification process;

FIG. **3** is a flowchart of a service preemption identification process;

FIG. **4** is a network diagram of a network with various SNCs equipped on the links;

FIG. **5** is a flowchart of a first preemption SNC selection process;

FIG. **6** is a flowchart of a second preemption SNC selection process;

FIG. **7** is a flowchart of a third preemption SNC selection process;

FIG. **8** is a flowchart of a fourth preemption SNC selection process;

FIG. **9** is a flowchart of a fifth preemption SNC selection process;

FIG. **10** is a flowchart of a sixth preemption SNC selection process;

FIG. **11** is a flowchart of a seventh preemption SNC selection process;

FIG. **12** is a flowchart of an eighth preemption SNC selection process;

FIG. **13** is a flowchart of a ninth preemption SNC selection process;

FIG. **14** is a flowchart of a tenth preemption SNC selection process;

FIG. **15** is a block diagram of an exemplary node for use with the systems and methods described herein;

FIG. **16** is a block diagram of a controller to provide control plane processing and/or operations, administration, maintenance, and provisioning (OAM&P) for the node, and/or to implement a Software Defined Networking (SDN) controller; and

FIG. **17** is a flowchart of a process of service preemption selection implemented by a node in a network.

DETAILED DESCRIPTION OF THE DISCLOSURE

In various exemplary embodiments, service preemption selection systems and methods are described for circuit-based control planes, SDN, and hybrid control plane networks. The systems and methods provide an ability to look backward and forward to more intelligently choose services to preempt on the local link, thereby reducing the number of services preempted. Again, the systems and methods could be applied to both network level control planes such as ASON, GMPLS, etc. with local knowledge, and to SDN controller based systems to choose services to preempt based on the overriding criteria of reducing network instability.

Exemplary Network

Referring to FIG. **1**A, in an exemplary embodiment, a network diagram illustrates an exemplary network **10** with various interconnected nodes **12** (illustrated as nodes **12**A-**12**J). The nodes **12** are interconnected through a plurality of links **14**. The nodes **12** communicate with one another over the links **14** through Layer 0 (L0), Layer 1 (L1), Layer 2 (L2), and/or Layer 3 (L3) protocols. The nodes **12** can be network elements which include a plurality of ingress and egress ports forming the links **12**. An exemplary node implementation is illustrated in FIG. **15**. The network **10** can include various services between the nodes **12**. Each service can be at any of the L0, L1, L2, and/or L3 protocols, such as a wavelength, an SNC, an LSP, etc., and each service is an end-to-end path or an end-to-end signaled path and from the view of the client signal contained therein, it is seen as a single network segment. The nodes **12** can also be referred to interchangeably as network elements (NEs). The network **10** is illustrated, for example, as an interconnected mesh network, and those of ordinary skill in the art will recognize the network **10** can include other architectures, with additional nodes **12** or with fewer nodes **12**, etc.

The network **100** can include a control plane **16** operating on and/or between the nodes **12**. The control plane **16** includes software, processes, algorithms, etc. that control configurable features of the network **10**, such as automating discovery of the nodes **12**, capacity on the links **14**, port availability on the nodes **12**, connectivity between ports; dissemination of topology and bandwidth information between the nodes **12**; calculation and creation of paths for connections; network level protection and restoration; and the like. In an exemplary embodiment, the control plane **16** can utilize ASON, GMPLS, OSRP, MPLS, Open Shortest Path First (OSPF), Intermediate System-Intermediate System (IS-IS), or the like. Those of ordinary skill in the art will recognize the network **10** and the control plane **16** can utilize any type of control plane for controlling the nodes **12** and establishing connections between the nodes **12**.

An SDN controller **18** can also be communicatively coupled to the network **10** through one or more of the nodes **12**. SDN is an emerging framework which includes a centralized control plane decoupled from the data plane. SDN provides the management of network services through abstraction of lower-level functionality. This is done by decoupling the system that makes decisions about where traffic is sent (the control plane) from the underlying systems that forward traffic to the selected destination (the data plane). SDN works with the SDN controller **18** knowing a full network topology through configuration or through the use of a controller-based discovery process in the network **10**. The SDN controller **18** differs from a management system in that it controls the forwarding behavior of the nodes **12** only, and performs control in real time or near real time, reacting to changes in services requested, network traffic analysis and network changes such as failure and degradation. Also, the SDN controller **18** provides a standard northbound interface to allow applications to access network resource information and policy-limited control over network behavior or treatment of application traffic. The SDN controller **18** sends commands to each of the nodes **12** to control matching of data flows received and actions to be taken, including any manipulation of packet contents and forwarding to specified egress ports. Examples of SDN include OpenFlow (www.opennetworking org/sdn-resources/onf-specifications/openflow/), General Switch Management Protocol (GSMP) defined in RFC 3294 (June 2002), and Forwarding and Control Element Separation (ForCES) defined in RFC 5810 (March 2010), the contents of all are incorporated by reference herein.

Note, the network **10** can use the control plane **16** separately from the SDN controller **18**. Alternatively, the network **10** can use the SDN controller **18** separately from the control plane **16**. In another exemplary embodiment, the control plane **16** can operate in a hybrid control mode with the SDN controller **18**. In this scheme, for example, the SDN controller **18** does not necessarily have a complete view of the network **10**. Here, the control plane **16** can be used to manage services in conjunction with the SDN controller **18**.

In the terminology of ASON and OSRP, sub-network connections (SNC) are end-to-end signaled paths since from the point of view of a client signal, each is a single network segment. In GMPLS, the connections are an end-to-end path referred to as LSPs. For example, LSPs for GMPLS are described in draft-ietf-ccamp-gmpls-ospf-g709v3-13, "Traffic Engineering Extensions to OSPF for Generalized MPLS (GMPLS) Control of Evolving G.709 OTN Networks," (Dec. 11, 2013), the contents of which are incorporated by reference herein. In SDN, such as in OpenFlow, services are called "flows." In the various descriptions herein, reference is made to SNCs for illustration only of an exemplary embodiment of the systems and methods. Those of ordinary skill in the art will recognize that SNCs, LSPs, flows, or any other managed service in the network can be used with the systems and methods described herein for end-to-end paths. Also, as described herein, the term services is used for generally describing connections such as SNCs, LSPs, flows, etc. in the network **10**.

In an exemplary embodiment, the network **10** can be configured to perform service preemption selection by one or more nodes **12**. The network **10** can include a plurality of nodes interconnected to one another by a plurality of links; wherein an intermediate node is configured to receive, from an ingress link, a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request includes a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link, select, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria, and forward the request on an egress link to an adjacent node with any updates based on the selecting. The one or more services for preemption can be selected with the list including a backward view of the previously selected services for preemption and a limited forward view where the intermediate node performs the selecting at a far end of the ingress link. The intermediate

node can be configured to determine whether preemption is required on the egress link, and if required, provide an indication of whether preemption is required on the egress link prior to forwarding to the adjacent node. The network can utilize one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller.

Preemption Cascading

Referring to FIGS. **1**B-**1**D, in various exemplary embodiments, network diagrams illustrate the network **10** and an exemplary preemption operation. In FIG. **1**B, a message **20** is to the node **12**A which in turn sends the message **20** to the node **12**B. The message **20** is a message instructing each node to preempt services to free up bandwidth on local links for higher priority messages. In ASON, OSRP, etc., the message **20** can be a SETUP message. In GMPLS, etc., the message **20** can be a CONNECTION REQUEST, and in SDN, the message **20** can be a message from the SDN controller **18**. In FIG. **1**B, responsive to the message **20**, the node **12**A preempts services **22**, **24**. The service **22** is between the nodes **12**A, **12**H, and the service **24** is between the nodes **12**A, **12**D. In FIG. **1**C, the message **20** is further forwarded to the node **12**C and the node **12**B preempts a service **26**, which is between the nodes **12**B, **12**J. Finally in FIG. **1**D, the message **20** is further forwarded to the node **12**D, and the node **12**C preempts a service **28**, which is between the nodes **12**C, **12**F. The preemption causes a cascading effect as lower priority SNCs are preempted, released, and attempt to restore in the network **10**. Note, each of the nodes **12**A, **12**B, **12**C is making local decisions, independent of one another and without the visibility of one another. It is desirable to preempt the least number of services while allowing the preempted services to mesh restore. In this manner, the systems and methods seek to maintain the local decisions, but with additional information, from adjacent nodes. The adjacent nodes are from the perspective of the path of the message **20**, i.e., the preceding node and the subsequent node.

Again, the preemption of established services causes increased instabilities as the preempted services attempt to restore. Thus, the systems and methods limit the number of services affected by the preempted services. In a distributed control plane with a limited network view such as GMPLS or ASON, the network elements do not have visibility of all services paths in the network. While the originating network element can choose the lowest cost path for a service based on knowledge of available bandwidth at a particular priority level on individual links, it does not have knowledge of the services on those links (to which the originating network element is not adjacent); only the intermediate network elements adjacent to the link know this information. Therefore, conventionally, the originating network element cannot choose which services to preempt on individual links across the network. Conventionally, the message **20** is sent without the knowledge of how much instability the action will cause. The decision of which services to preempt is made by the intermediate network elements. These intermediate network elements have no knowledge of service paths other than the two links in the preempting service path connected to that network element. Similar to the originating network element, the decision of which services to preempt on these links may not be optimal due to this lack of network visibility.

SDN utilizing a centralized controller may have a better view of the network **10** allowing for more informed decisions of the preemption path and the services to preempt. However, the level of knowledge may not be complete or may be inaccurate; especially in the case of hybrid control with a distributed control plane overseen by a centralized controller where the network elements are given some level of control when restoring services.

In various exemplary embodiment, the systems and methods use innovations to choose more intelligently services to preempt on a local link, between two network elements. First, the message received at the two network elements of the local link includes a list of the services already chosen for preemption earlier in the preempting service path. This allows the local network elements to determine if any services present on the local link will already be preempted due to the prior decision in the preempting service setup. This knowledge allows the local link network elements to assign the bandwidth of these services to the preempting service. This allocation may prevent or reduce the number of services needed to be preempted on the local link.

The second innovation allows a limited forward view of the preempting service path. The first network element on the local link indicates the need for preemption on the local link but does not choose the services to preempt. Instead, the decision is made by the second network element on the local link which has visibility of the next link in the preempting service path. If the next link also requires preemption, the second network element can identify common services to both links to preempt, thus reducing the number of services preempted. The second network element then updates the preempted service list in the message **20**, and forwards it down the preempting service path where the process is repeated. Thus, these two techniques allow a network element to select services to preempt based on additional knowledge, i.e., the list of previously selected services to preempt and a forward view in that service preemption for any local link is performed by a far end network element.

The systems and methods directly address the distributed control plane and the SDN hybrid control plane cases. In both cases, the originating and intermediate network elements do not have a complete view of the network. In the hybrid case, this occurs in two possible scenarios. First, if the network does not advertise services on individual lines within an aggregated link, the centralized controller cannot efficiently choose the services to preempt on individual links. This is because it cannot know to which lines within the link the preempting services will be assigned. This decision is made locally by the network elements. Second, if the network elements are allowed to perform route calculation during mesh restoration for improved restoration performance, the centralized controller may not immediately know where the services are in the network. This can occur if the originating network element exhausts all protect routes provided by the centralized controller.

A third innovation is described to address the SDN hybrid case. While the centralized controller may not have a complete view of the network, it does have a much better view of than the originating network element; by having knowledge of the services on each link. Using this knowledge, it can prioritize services to be preempted on a link by giving weight to services with along the preempting service path. The list of services to prioritize for preemption can be included in the message **20** and allow network elements to make a more informed decision.

Service Preemption Signal Flow Process

Referring to FIG. **2**, in an exemplary embodiment, a flowchart illustrates a service preemption signal flow process **30**. The service preemption signal flow process **30** is illustrated with reference to a network **10**A including nodes **12**A, **12**B, **12**C, interconnected by links **14**AB, **14**BC. The

service preemption path is from the node **12**A to the node **12**B to the node **12**C. Also, for illustration purposes, the service preemption signal flow process **30** is illustrated with reference to ASON/OSRP with the message **20** as a SETUP message and the services as SNCs. The message **20** is transmitted to the node **12**A which receives the SETUP message with a preemption request and a preempted SNC list (step **32**). The preemption request is to cause preemption to free up bandwidth on the local link **14**AB, and the preempted SNC list includes a view of what SNCs previous nodes **12** have selected. Note, the SETUP message can include both a request for a new SNC and a request to preempt other SNCs for the new SNC.

The node **12**A determines if the link **14**AB requires preemption (step **34**). This is determine based on the bandwidth required in the preemption request and the current bandwidth on the link **14**AB. If the link **14**AB does not require preemption, the node **12**A proceeds with normal SETUP behavior, for the new SNC, and forwards the SETUP message to the node **12**B (step **36**). If the link **14**AB needs preemption, e.g., to support the new SNC, the node **12**A indicates a preemption request on the link **14**AB, in the SETUP message, and forwards the SETUP message to the node **12**B (step **38**).

The node **12**B receives the SETUP message from the node **12**A with the preemption request, the preempted SNC list, and a preemption flag for the link **14**AB (step **40**). The preemption flag was set in the steps **36**, **38** by the node **12**A, and the preemption flag determines whether or not the link **14**AB or the link **14**BC requires preemption (step **42**). If the link **14**AB does not need preemption, the node **12**B proceeds with normal SETUP behavior (step **44**). If the link **14**AB needs preemption, the node **12**B identifies the SNCs to preempt on the link **14**AB and appends the identified SNCs to the preempted SNC list (step **46**). Note, identification of the SNCs for preemption is further described in FIG. **3**.

The node **12**B next determines if the link **14**BC requires preemption (step **48**). If the link **14**BC does not require preemption, the node **14**B proceeds with normal SETUP behavior (step **50**). If the link **14**BC requires preemption, the node **14**B indicates a preemption request on the link **14**BC in the SETUP message (step **52**). The node **12**B forwards the SETUP message with the updated preempted SNC list and with or without the preemption flag for the link **14**BC. The node **12**C, which is the terminating node, receives the SETUP message and transmits a CONNECT message with the preempted SNC list. The CONNECT message is sent towards the node **12**A, and it releases the preempted SNCs on all nodes **12**A, **12**B, **12**C in the path (step **54**).

Service Preemption Identification Process

Referring to FIG. **3**, in an exemplary embodiment, a flowchart illustrates a service preemption identification process **60**. The service preemption identification process **60** is illustrated with reference to a network **10**A including nodes **12**A, **12**B, **12**C. The service preemption path is from the node **12**A to the node **12**B to the node **12**C. The service preemption identification process **60** can operate with the service preemption signal flow process **30**. The service preemption identification process **60** assumes there is a need for preemption on the link **14**AB. Continuing from step **40**, the node **12**B receives the SETUP message with the preemption request and the preempted SNC list (step **62**). The node **12**B checks to see if the preempted SNC list provides sufficient bandwidth on the link **14**AB based on the preemption request (step **64**). If the preempted SNC list provides sufficient bandwidth, the node **12**B uses the preempted SNC list to identify the SNCs to be preempted on the link **14**AB (step **66**). Here, the node **12**B selects SNCs to preempt on the link **14**AB based on SNCs that have already been selected by previous nodes.

If the preempted SNC list does not provide sufficient bandwidth, the node **12**B determines in the link **14**BC needs preemption (step **68**). If the link **14**BC does not need preemption, the node **12**B chooses the least number of SNCs from the link **14**AB to meet the bandwidth requirements (step **70**). Here, since there is no forward requirement for preemption on the link **14**BC and because the previously preempted SNCs do not affect the link **14**AB, the node **12**B can choose what SNCs to preempt on the link **14**AB based solely on information associated with the link **14**AB. If the link **14**BC also needs preemption, the node **12**B uses a list of common SNCs for the links **14**AB, **14**BC to choose the SNCs for preemption based on priority and a least number of SNCs (step **72**). Here, the previously preempted SNCs do not affect the link **14**AB, but there is also a need for preemption on the link **14**BC, accordingly, the node **12**B can choose common SNCs between the links **14**AB, **14**BC to minimize the number of overall SNCs preempted.

After step **72**, the node **12**B determines if the bandwidth requirement is met for the link **14**AB, based on the preemption of common SNCs between the links **14**AB, **14**BC (step **74**). If not, the node **12**B goes to step **70**. If the bandwidth requirement is met and after step **66**, the node **12**B adds the preempted SNCs in the preempted SNC list and forwards the SETUP message forward (step **76**).

The nodes **12**A, **12**B, **12**C can choose which services to preempt based on a hierarchical approach which has criteria for optimally selecting the services. For example, the service selection criteria can include:

1. SNC in SETUP Message Preempted List (i.e., already preempted)
2. SNC sharing common path with Preempting SNC Downstream
3. SNC with Lowest Priority
4. SNC with Lowest Rate/Number of SNCs (i.e., Total Rate)
5. SNC with Lowest Incarnation Number

The criteria select SNCs (services) intelligently to minimize the number of affected services in preemption. By first selecting SNCs which have already been selected by downstream nodes, the criteria avoids disrupting SNCs where possible. Second, by selecting SNCs sharing a common part with the preempting SNC downstream, the criteria selects the best SNC to minimize again disrupting SNCs where possible. The first two criteria selects SNCs based on previous decisions (downstream) and based on the common path upstream. These two criteria make the SNC selection not merely a local decision with the expectation of minimization of SNCs where possible. The third through fifth criteria is based solely on local information at the node.

The service preemption signal flow process **30** and the service preemption identification process **60** can operate with a control plane, e.g., a distributed control plane where the originating network element can initiate the message **20** and the intermediate network elements can perform various aspects of the processes **30**, **60**. In an SDN and control plane hybrid network, the controller may perform the route calculation instead of the originating network element and provide the protection route to the originating network element. In this case, the controller can take into account existing SNCs along the preempting SNCs path. While the controller cannot choose specific SNCs to preempt on individual links, the controller can suggest SNCs to preempt and pass this information to the network elements in the SETUP

message. These SNCs should be prioritized in choosing the SNC(s) to preempt by the intermediate network elements.

The SNCs present on the preempted SNC list should be chosen for preemption on the local link since these SNCs can be preempted, and their bandwidth can become available. The SNCs on the first and second links available for preemption can be classified by preemption criteria and ordered into two lists. The preemption criteria may be based on the presence on the priority list provided by the centralized controller, SNC Holding Priority, SNC Size/Rate, and SNC Quantity. Common SNCs to both lists can be chosen for preemption first, with an emphasis of preempting the least number of SNCs to meet the current bandwidth necessary to setup the Preempting SNC. Any additional bandwidth required can need to be chosen from SNCs not common to both links. SNCs chosen for Preemption can be reserved for the specific Preempting SNC, but not released.

When the preempting SNCs SETUP message reaches the terminating network element, the preempted SNC list is transferred to the CONNECT message and returned along the preempting SNCs setup path. The preempted SNC list includes all the decisions made by the intermediate network elements across all links in the path. While the preempted SNCs were identified and reserved during the setup phase, the CONNECT message sent by the terminating network element actually triggers the release of these SNCs. This prevents the unnecessary release of preempted SNCs in the case of a failed setup of the preempting SNC. The terminating network element cannot enhance the preempted SNC list, as it does not have any more information about the links in the path than the originating or intermediate network elements.

At the node **12**B, the link **14**AB can be referred to as an ingress link and the link **14**BC can be referred to as an egress link. The node **12**A is responsible for determining whether or not preemption is required for the link **14**AB and to signal such requirement to the node **12**B. The node **12**B, on the other hand, is responsible for determining which services are preempted on the link **14**AB. Conversely, the node **12**B is responsible for determining whether or not preemption is required on the link **14**BC and to signal such requirement to the node **12**C. In addition to the far end node selecting services, the message **20** includes a history of any previously selected services. In this manner, the selection of services for preemption is done forward-looking as well as backward looking Backward looking in that the selecting node has a list of already selected services—which optimally can be selected again to minimize impacted services. Forward-looking in that the selecting node is at the end of the link, not the beginning

Preemption Identification Procedure Examples

Referring to FIGS. **4-14**, in various exemplary embodiments, network diagrams illustrate various examples of preemption identification in the network **10**A. FIG. **4** illustrates the network **10**A with various SNCs equipped on the links **14**AB, **14**BC. In these examples, the services are SNCs and the bandwidth is in terms of Optical channel Data Unit k (ODUk) where k=0, 1, 2, or 3. Of course, the network **10**A and the preemption selection systems and methods contemplate any services. The SNCs are ordered by Holding Priority (HP), SNC size, and SNC rate. For illustration purposes, the SNCs are referred to as Green, Red, and Blue (SNCs **80**, **82**, **84**, respectively). The link **14**AB includes the Blue SNC **84** which is **2**xODU**0** with an HP of 7, the Red SNC **82** which is **2**xODU**0** with an HP of 4, and the Green SNC **80** which is **1**xODU**2** with an HP of 4. The link **14**BC includes the Red SNC **82** and the Green SNC **80**. Note, for example, the higher the HP in value, the lower the HP is. For example, the Green SNC **80** with an HP of 4 is a higher priority than the Blue SNC **80** with an HP of 7.

Once the SNCs on the two links **14**AB, **14**BC are ordered, identifying the SNCs to preempt should proceed by choosing the least number of SNCs which meets the bandwidth requirements of both the links **14**AB, **14**BC without going over. For instance, in the example where the preempting SNC is an ODU**2**, the node **12**B should choose the Green SNC **80** because preempting the ODU**0** SNCs will not meet the bandwidth required on the link **14**BC even though the Green SNC **80** has a higher Holding Priority.

FIG. **5** is a flowchart of a first preemption SNC selection process **100**. In the process **100**, the message **20** includes a preempted SNC list with the Blue SNC **84**. The node **12**A receives the SETUP message **20** with the preempted SNC list with the Blue SNC **84** (step **102**). The node **12**A indicates preemption is required on the link **14**AB and forwards the SETUP message **20** to the node **12**B (step **104**). The node **12**B subsequently receives the SETUP message **20** with the preempted SNC list with the Blue SNC **84**, and a preemption indication from the node **12**A (step **106**). The node **12**B verifies the Blue SNC **84** resources will provide adequate bandwidth on the link **14**AB for the preempting SNC (step **108**), and the node **12**B forwards the SETUP message **20** to the node **12**C (step **110**).

FIG. **6** is a flowchart of a second preemption SNC selection process **130**. In the process **130**, the message **20** includes an empty preempted SNC list. The node **12**A receives the SETUP message **20** with the empty preempted SNC list (step **132**). The node **12**A indicates preemption on the link **14**AB and forwards the SETUP message **20** to the node **12**B (step **134**). The node **12**B receives the SETUP message **20** with the empty preempted SNC list and the preemption indication from the node **12**A (step **136**). The node **12**B chooses the Blue SNC **84** to provide bandwidth on the link **14**AB for the preempting SNC due to SNC Holding Priority, and the node **12**B determines the Blue SNC **82** resources will provide adequate bandwidth on the link **14**AB for the preempting SNC (step **138**). The node **12**B updates the preempting SNC list and forwards the SETUP message **20** to the node **12**C (step **140**).

FIG. **7** is a flowchart of a third preemption SNC selection process **160**. In the process **160**, the message **20** includes the Green SNC **80**. The node **12**A receives the SETUP message **20** with the SNC preempted list with the Green SNC **80** (step **162**). The node **12**A indicates preemption on the link **14**AB and forwards the SETUP message **20** to the node **12**B (step **164**). The node **12**B receives the SETUP message **20** with the SNC preempted list with the Green SNC **80** and the preemption indication from the node **12**A (step **166**). The node **12**B verifies the Green SNC **80** resources will provide adequate bandwidth on the link **14**AB for the preemption SNC, and because this is the case, no additional preemption is necessary (step **168**). The node **12**B forwards the SETUP message **20** to the node **12**C (step **170**). The Green SNC **80** resources are used on the link **14**AB even though the Blue SNC **84** Holding Priority is lower because the Green SNC **80** is already present on the preempted SNC List.

FIG. **8** is a flowchart of a fourth preemption SNC selection process **200**. In the process **200**, the message **20** includes an empty preempted SNC list. The node **12**A receives the SETUP message **20** with the empty preempted SNC list or a list with no SNCs present on the link **14**AB (step **202**). For example, if the preempted SNC list has SNCs included, but none is present on the link **14**AB, this would be the equivalent of an empty preempted SNC list. The node

12A indicates preemption on the link 14AB and forwards the SETUP message 20 to the node 12B (step 204). The node 12B receives the SETUP message 20 with the preempted SNC list and the preemption indication from the node 12A (step 206). The node 12B determines preemption is needed on the link 14BC and collects the set of SNCs common to the links 14AB, 1BC (step 208). From this set, the node 12B chooses the Green SNC 80 due to the common path to provide bandwidth on the link 14AB for the preempting SNC, and the node 12B determines the Green SNC 80 resources will provide adequate bandwidth on the link 14AB for the preempting SNC (step 210). The node 12B updates the preempted SNC list and forwards the SETUP message 20 to the node 12C (step 212).

FIG. 9 is a flowchart of a fifth preemption SNC selection process 230. In the process 230, the message 20 includes an empty preempted SNC list. The node 12A receives the SETUP message with the empty preempted SNC list or with a list with no SNCs present on the link 14AB (step 232). The node 12A indicates preemption on the link 14AB and forwards the SETUP message 20 to the node 12B (step 234). The node 12B receives the SETUP message 20 with the preempted SNC list and the preemption indication from the node 12A (step 236). The node 12B chooses the Blue SNC 84 to provide bandwidth on the link 14AB for the preempting SNC due to the SNC Holding Priority, and determines the Blue SNC 84 resources will provide adequate bandwidth on the link 14AB for the preempting SNC (step 238). The node 12B updates the preempted SNC list and forwards the SETUP message 20 to the node 12C (step 240).

FIG. 10 is a flowchart of a sixth preemption SNC selection process 260. In the process 260, the message 20 includes an empty preempted SNC list. Also, in this example, the Blue SNC 84 includes 8xODU0 on the link 14AB and 4xODU0 on the link 14BC. The node 12A receives the SETUP message with the empty preempted SNC list or with a list with no SNCs present on the link 14AB (step 262). The node 12A indicates preemption on the link 14AB and forwards the SETUP message 20 to the node 12B (step 264). The node 12B receives the SETUP message 20 with the preempted SNC list and the preemption indication from the node 12A (step 266). The node 12B determines no preemption is needed on the link 14BC (step 268). The node 12B chooses the 4xODU0 Blue SNCs 84 to provide bandwidth on the link 14AB for the preempting SNC, and determines the 4xODU0 Blue SNCs 84 resources will provide adequate bandwidth on the link 14AB for the preempting SNC (step 270). The node 12B updates the preempted SNC list and forwards the SETUP message 20 to the node 12C (step 272).

FIG. 11 is a flowchart of a seventh preemption SNC selection process 300. In the process 300, the message 20 includes an empty preempted SNC list. Also, in this example, the Blue SNC 84 includes 8xODU0 on the link 14AB and 4xODU0 on the link 14BC. The node 12A receives the SETUP message with the empty preempted SNC list or with a list with no SNCs present on the link 14AB (step 302). The node 12A indicates preemption on the link 14AB and forwards the SETUP message 20 to the node 12B (step 304). The node 12B receives the SETUP message 20 with the preempted SNC list and the preemption indication from the node 12A (step 306). The node 12B determines no preemption is needed on the link 14BC (step 308). The node 12B chooses the two Blue SNCs 84, i.e., the 8xODU0 on the link 14AB and the 4xODU0 on the link 14BC, due to a lower Holding Priority to provide bandwidth on the link 14AB for the preempting SNC, and determines the two Blue SNCs 84 resources will provide adequate bandwidth on the link 14AB for the preempting SNC (step 310). The node 12B updates the preempted SNC list and forwards the SETUP message 20 to the node 12C (step 312).

FIG. 12 is a flowchart of an eighth preemption SNC selection process 330. In the process 330, the message 20 includes an empty preempted SNC list. Also, in this example, the Blue SNC 84 includes 8xODU0 on the link 14AB and 4xODU0 on the link 14BC. The node 12A receives the SETUP message with the empty preempted SNC list or with a list with no SNCs present on the link 14AB (step 332). The node 12A indicates preemption on the link 14AB and forwards the SETUP message 20 to the node 12B (step 334). The node 12B receives the SETUP message 20 with the preempted SNC list and the preemption indication from the node 12A (step 336). The node 12B determines no preemption is needed on the link 14BC (step 338). The node 12B chooses the Green SNC 80 due to the least amount of SNCs preempted to provide bandwidth on the link 14AB for the preempting SNC, and determines the Green SNC 80 resources will provide adequate bandwidth the link 14AB for the preempting SNC (step 340). The node 12B updates the preempted SNC list and forwards the SETUP message 20 to the node 12C (step 342).

FIG. 13 is a flowchart of a ninth preemption SNC selection process 350. In the process 350, the message 20 includes an empty preempted SNC list. Also, in this example, the Blue SNC 84 includes 8xODU0 on the link 14AB and 4xODU0 on the link 14BC. The node 12A receives the SETUP message with the empty preempted SNC list or with a list with no SNCs present on the link 14AB (step 352). The node 12A indicates preemption on the link 14AB and forwards the SETUP message 20 to the node 12B (step 354). The node 12B receives the SETUP message 20 with the preempted SNC list and the preemption indication from the node 12A (step 356). The node 12B determines preemption is needed on the link 14BC and collects the set of SNCs common to the links 14AB, 14BC (step 358). From this list, the node 12B chooses the Green SNC 80 due to the common path to provide bandwidth on the link 14AB for the preempting SNC, and determines the Green SNC 80 resources will provide adequate bandwidth on the link 14AB for the preempting SNC (step 360). The node 12B updates the preempted SNC list and forwards the SETUP message 20 to the node 12C (step 362).

FIG. 14 is a flowchart of a tenth preemption SNC selection process 380. In the process 380, the message 20 includes an empty preempted SNC list. Also, in this example, the Blue SNC 84 includes 8xODU0 on the link 14AB and 4xODU0 on the link 14BC. The node 12A receives the SETUP message with the empty preempted SNC list or with a list with no SNCs present on the link 14AB (step 382). The node 12A indicates preemption on the link 14AB and forwards the SETUP message 20 to the node 12B (step 384). The node 12B receives the SETUP message 20 with the preempted SNC list and the preemption indication from the node 12A (step 386). The node 12B determines preemption is needed on the link 14BC and collects the set of SNCs common to the links 14AB, 14BC (step 388). From this list, the node 12B chooses the Green SNC 80 due to the bandwidth need for the links 14AB, 14BC to provide bandwidth on the link 14AB for the preempting SNC, and determines the Green SNC 80 resources will provide adequate bandwidth on the link 14AB for the preempting SNC (step 390). The node 12B updates the preempted SNC list and forwards the SETUP message 20 to the node 12C (step 392).

Exemplary Network Element/Node

Referring to FIG. **15**, in an exemplary embodiment, a block diagram illustrates an exemplary node **400** for use with the systems and methods described herein. In an exemplary embodiment, the exemplary node **400** can be a network element that may consolidate the functionality of a Multi-Service Provisioning Platform (MSPP), Digital Cross Connect (DCS), Ethernet and/or Optical Transport Network (OTN) switch, Wave Division Multiplexed (WDM)/Dense WDM (DWDM) platform, etc. into a single, high-capacity intelligent switching system providing Layer 0, 1, and/or 2 consolidation. In another exemplary embodiment, the node **400** can be any of an OTN Add/Drop Multiplexer (ADM), a Multi-Service Provisioning Platform (MSPP), a Digital Cross-Connect (DCS), an optical cross-connect, an optical switch, a router, a switch, a Wavelength Division Multiplexing (WDM) terminal, an access/aggregation device, etc. That is, the node **400** can be any digital system with ingress and egress digital signals and switching of channels, timeslots, tributary units, etc. While the node **400** is generally shown as an optical network element, the systems and methods contemplated for use with any switching fabric, network element, or network based thereon.

In an exemplary embodiment, the node **400** includes common equipment **410**, one or more line modules **420**, and one or more switch modules **430**. The common equipment **410** can include power; a control module; operations, administration, maintenance, and provisioning (OAM&P) access; user interface ports; and the like. The common equipment **410** can connect to a management system **450** through a data communication network **460** (as well as a Path Computation Element (PCE), Software Defined Network (SDN) controller, OpenFlow controller, etc.). The management system **450** can include a network management system (NMS), element management system (EMS), or the like. Additionally, the common equipment **410** can include a control plane processor, such as a controller **500** illustrated in FIG. **16** configured to operate the control plane as described herein. The node **400** can include an interface **470** for communicatively coupling the common equipment **410**, the line modules **420**, and the switch modules **430** to one another. For example, the interface **470** can be a backplane, midplane, a bus, optical or electrical connectors, or the like. The line modules **420** are configured to provide ingress and egress to the switch modules **430** and to external connections on the links to/from the node **400**. In an exemplary embodiment, the line modules **420** can form ingress and egress switches with the switch modules **430** as center stage switches for a three-stage switch, e.g. a three-stage Clos switch. Other configurations and/or architectures are also contemplated. The line modules **420** can include optical transceivers, such as, for example, 1 Gb/s (GbE PHY), 2.5 GB/s (OC-**48**/STM-**1**, OTU**1**, ODU**1**), 10 Gb/s (OC-**192**/STM-**64**, OTU**2**, ODU**2**, 10 GbE PHY), 40 Gb/s (OC-**768**/STM-**256**, OTU**3**, ODU**3**, 40 GbE PHY), 100 Gb/s (OTU**4**, ODU**4**, 100 GbE PHY), ODUflex, Flexible Ethernet, etc.

Further, the line modules **420** can include a plurality of optical connections per module and each module may include a flexible rate support for any type of connection, such as, for example, 155 MB/s, 622 MB/s, 1 GB/s, 2.5 GB/s, 10 GB/s, 40 GB/s, and 100 GB/s, N×1.25 GB/s, and any rate in between as well as future higher rates. The line modules **420** can include wavelength division multiplexing interfaces, short reach interfaces, and the like, and can connect to other line modules **420** on remote network elements, end clients, edge routers, and the like, e.g. forming connections on the links in the network **100**. From a logical perspective, the line modules **420** provide ingress and egress ports to the node **400**, and each line module **420** can include one or more physical ports. The switch modules **430** are configured to switch channels, timeslots, tributary units, packets, etc. between the line modules **420**. For example, the switch modules **430** can provide wavelength granularity (Layer 0 switching); OTN granularity such as Optical Channel Data Unit-**1** (ODU**1**), Optical Channel Data Unit-**2** (ODU**2**), Optical Channel Data Unit-**3** (ODU**3**), Optical Channel Data Unit-**4** (ODU**4**), Optical Channel Data Unit-flex (ODUflex), Optical channel Payload Virtual Containers (OPVCs), ODTUGs, etc.; Ethernet granularity; and the like. Specifically, the switch modules **430** can include Time Division Multiplexed (TDM) (i.e., circuit switching) and/or packet switching engines. The switch modules **430** can include redundancy as well, such as 1:1, 1:N, etc. In an exemplary embodiment, the switch modules **430** provide OTN switching and/or Ethernet switching.

Those of ordinary skill in the art will recognize the node **400** can include other components which are omitted for illustration purposes, and that the systems and methods described herein are contemplated for use with a plurality of different network elements with the node **400** presented as an exemplary type of network element. For example, in another exemplary embodiment, the node **400** may not include the switch modules **430**, but rather have the corresponding functionality in the line modules **420** (or some equivalent) in a distributed fashion. For the node **400**, other architectures providing ingress, egress, and switching are also contemplated for the systems and methods described herein. In general, the systems and methods described herein contemplate use with any network element providing switching of channels, timeslots, tributary units, wavelengths, etc. and using the control plane. Furthermore, the node **400** is merely presented as one exemplary node **400** for the systems and methods described herein.

In an exemplary embodiment, the node **400** is in the network **10** and configured to perform service preemption selection. The node **400** can include a first port coupled to an ingress link, wherein the first port is configured to receive a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request includes a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link; a controller configured to select, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria; and a second port configured to forward the request on an egress link to an adjacent node with any updates based on the one or more services for preemption. The ports can be part of the line modules **420** and the controller can be part of the common equipment **410**. The one or more services for preemption can be selected with the list including a backward view of the previously selected services for preemption and a limited forward view where the node performs the selecting at a far end of the ingress link. The controller can be further configured to determine whether preemption is required on the egress link, and if required, providing an indication of whether preemption is required on the egress link prior to the second port forwarding the forward the request on the egress link. The updates can include the addition of the one or more services for preemption in the request.

The service selection criteria can be a hierarchical approach for determining the one or more services for preemption based first on the list, second on a common path between the ingress link and the egress link, and third based

on characteristics of the one or more services for preemption. The network can utilize one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller. The network can utilize a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller, and wherein the SDN controller provides suggestions for how the controller selects the one or more services for preemption. The node and each intermediate node in the network for the service can be configured to perform the preemption, and wherein the list can be utilized to select previously selected services to minimize disruption in the network.

Exemplary Controller

Referring to FIG. **16**, in an exemplary embodiment, a block diagram illustrates a controller **500** to provide control plane processing and/or operations, administration, maintenance, and provisioning (OAM&P) for the node **400**, and/or to implement a Software Defined Networking (SDN) controller. The controller **500** can be part of the common equipment, such as common equipment **410** in the node **400**, or a stand-alone device communicatively coupled to the node **400** via the DCN **460**. In a stand-alone configuration, the controller **500** can be an SDN controller, an NMS, a PCE, etc. The controller **500** can include a processor **510** which is a hardware device for executing software instructions such as operating the control plane. The processor **510** can be any custom made or commercially available processor, a central processing unit (CPU), an auxiliary processor among several processors associated with the controller **500**, a semiconductor-based microprocessor (in the form of a microchip or chip set), or generally any device for executing software instructions. When the controller **500** is in operation, the processor **510** is configured to execute software stored within memory, to communicate data to and from the memory, and to generally control operations of the controller **500** pursuant to the software instructions. The controller **500** can also include a network interface **520**, a data store **530**, memory **540**, an I/O interface **550**, and the like, all of which are communicatively coupled to one another and with the processor **510**.

The network interface **520** can be used to enable the controller **500** to communicate on the DCN **460**, such as to communicate control plane information to other controllers, to the management system **450**, to the nodes **400**, and the like. The network interface **520** can include, for example, an Ethernet card (e.g., 10BaseT, Fast Ethernet, Gigabit Ethernet) or a wireless local area network (WLAN) card (e.g., 802.11). The network interface **520** can include address, control, and/or data connections to enable appropriate communications on the network. The data store **530** can be used to store data, such as control plane information, provisioning data, OAM&P data, etc. The data store **530** can include any of volatile memory elements (e.g., random access memory (RAM, such as DRAM, SRAM, SDRAM, and the like)), nonvolatile memory elements (e.g., ROM, hard drive, flash drive, CDROM, and the like), and combinations thereof. Moreover, the data store **530** can incorporate electronic, magnetic, optical, and/or other types of storage media. The memory **540** can include any of volatile memory elements (e.g., random access memory (RAM, such as DRAM, SRAM, SDRAM, etc.)), nonvolatile memory elements (e.g., ROM, hard drive, flash drive, CDROM, etc.), and combinations thereof. Moreover, the memory **540** may incorporate electronic, magnetic, optical, and/or other types of storage media. Note that the memory **540** can have a distributed architecture, where various components are situated remotely from one another, but may be accessed by the processor **510**. The I/O interface **550** includes components for the controller **500** to communicate with other devices. Further, the I/O interface **550** includes components for the controller **500** to communicate with the other nodes, such as using overhead associated with OTN signals.

In an exemplary embodiment, the controller **500** is configured to communicate with other controllers **500** in the network **10** to operate the control plane for control plane signaling. This communication may be either in-band or out-of-band. For SONET networks and similarly for SDH networks, the controllers **500** may use standard or extended SONET line (or section) overhead for in-band signaling, such as the Data Communications Channels (DCC). Out-of-band signaling may use an overlaid Internet Protocol (IP) network such as, for example, User Datagram Protocol (UDP) over IP. In an exemplary embodiment, the controllers **500** can include an in-band signaling mechanism utilizing OTN overhead. The General Communication Channels (GCC) defined by ITU-T Recommendation G.709 are in-band side channels used to carry transmission management and signaling information within Optical Transport Network elements. The GCC channels include GCC**0** and GCC**1**/**2**. GCC**0** are two bytes within Optical Channel Transport Unit-k (OTUk) overhead that are terminated at every **3**R (Re-shaping, Re-timing, Re-amplification) point. GCC**1**/**2** are four bytes (i.e. each of GCC**1** and GCC**2** include two bytes) within Optical Channel Data Unit-k (ODUk) overhead. For example, GCC**0**, GCC**1**, GCC**2** or GCC**1**+2 may be used for in-band signaling or routing to carry control plane traffic. Based on the intermediate equipment's termination layer, different bytes may be used to carry control plane signaling. If the ODU layer has faults, it has been ensured not to disrupt the GCC**1** and GCC**2** overhead bytes and thus achieving the proper delivery control plane signaling. Other mechanisms are also contemplated for control plane signaling.

The controller **500** is configured to operate the control plane **16** in the network **10**. That is, the controller **500** is configured to implement software, processes, algorithms, etc. that control configurable features of the network **10**, such as automating discovery of the nodes, capacity on the links, port availability on the nodes, connectivity between ports; dissemination of topology and bandwidth information between the nodes; path computation and creation for connections; network level protection and restoration; and the like. As part of these functions, the controller **500** can include a topology database that maintains the current topology of the network **10** based on control plane signaling (e.g., HELLO messages) and a connection database that maintains available bandwidth on the links **14** again based on the control plane signaling. Again, the control plane is a distributed control plane; thus a plurality of the controllers **500** can act together to operate the control plane using the control plane signaling to maintain database synchronization. In source-based routing, the controller **500** at a source node for a connection is responsible for path computation and establishing by signaling other controllers **500** in the network **10**, such as through the SETUP message **20** which can include preemption. For example, the source node and its controller **500** can signal a path through various techniques such as Resource Reservation Protocol-Traffic Engineering (RSVP-TE) (G.7713.2), Private Network-to-Network Interface (PNNI), Constraint-based Routing Label Distribution Protocol (CR-LDP), etc. and the path can be signaled as a Designated Transit List (DTL) in PNNI or an Explicit Route Object (ERO) in RSVP-TE/CR-LDP. As

described herein, the connection refers to a signaled, end-to-end connection such as an SNC, SNCP, LSP, etc. which are generally a service. Path computation generally includes determining a path, i.e. traversing the links through the nodes from the originating node to the destination node based on a plurality of constraints such as administrative weights on the links, bandwidth availability on the links, etc. One aspect of path computation is preemption for a higher priority service.

Service Preemption Selection Process

Referring to FIG. **17**, in an exemplary embodiment, a flowchart illustrates a process **600** of service preemption selection implemented by a node in a network. The process **600** includes receiving, from an ingress link, a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request includes a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link (step **602**); selecting, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria (step **604**); and forwarding the request on an egress link to an adjacent node with any updates based on the selecting (step **606**). The process **600** can include determining whether preemption is required on the egress link, and if required, providing an indication of whether preemption is required on the egress link prior to the forwarding to the adjacent node (step **608**). The selecting can be performed with the list including a backward view of the previously selected services for preemption and a limited forward view where the node performs the selecting at a far end of the ingress link. The updates can include the addition of the one or more services for preemption in the request.

The service selection criteria can be a hierarchical approach for determining the one or more services for preemption based first on the list, second on a common path between the ingress link and the egress link, and third based on characteristics of the one or more services for preemption. The network can utilize one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller. The network can utilize a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller, and wherein the SDN controller provides suggestions for the selecting in the request. The node and each intermediate node in the network for the service can be configured to perform the selecting, and wherein the list is utilized to select previously selected services to minimize disruption in the network.

It will be appreciated that some exemplary embodiments described herein may include one or more generic or specialized processors ("one or more processors") such as microprocessors, digital signal processors, customized processors, and field programmable gate arrays (FPGAs) and unique stored program instructions (including both software and firmware) that control the one or more processors to implement, in conjunction with certain non-processor circuits, some, most, or all of the functions of the methods and/or systems described herein. Alternatively, some or all functions may be implemented by a state machine that has no stored program instructions, or in one or more application specific integrated circuits (ASICs), in which each function or some combinations of certain of the functions are implemented as custom logic. Of course, a combination of the aforementioned approaches may be used. Moreover, some exemplary embodiments may be implemented as a non-transitory computer-readable storage medium having computer readable code stored thereon for programming a computer, server, appliance, device, etc. each of which may include a processor to perform methods as described and claimed herein. Examples of such computer-readable storage mediums include, but are not limited to, a hard disk, an optical storage device, a magnetic storage device, a ROM (Read Only Memory), a PROM (Programmable Read Only Memory), an EPROM (Erasable Programmable Read Only Memory), an EEPROM (Electrically Erasable Programmable Read Only Memory), Flash memory, and the like. When stored in the non-transitory computer readable medium, software can include instructions executable by a processor that, in response to such execution, cause a processor or any other circuitry to perform a set of operations, steps, methods, processes, algorithms, etc.

Although the present disclosure has been illustrated and described herein with reference to preferred embodiments and specific examples thereof, it will be readily apparent to those of ordinary skill in the art that other embodiments and examples may perform similar functions and/or achieve like results. All such equivalent embodiments and examples are within the spirit and scope of the present disclosure, are contemplated thereby, and are intended to be covered by the following claims.

What is claimed is:

1. A method of service preemption selection implemented by a node in a network, the method comprising:

receiving, from an ingress link, a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request comprises a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link;

selecting, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria; and

forwarding the request on an egress link to an adjacent node with any updates based on the selecting,

wherein the network utilizes a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller, and wherein the SDN controller provides suggestions for the selecting in the request.

2. The method of claim **1**, wherein the selecting is performed with the list comprising a backward view of the previously selected services for preemption and a limited forward view where the node performs the selecting based in part on the egress link.

3. The method of claim **1**, further comprising:

determining whether preemption is required on the egress link, and if required, providing an indication of whether preemption is required on the egress link during the forwarding to the adjacent node.

4. The method of claim **1**, wherein the updates comprise addition of the one or more services for preemption in the request.

5. The method of claim **1**, wherein the service selection criteria is a hierarchical approach for determining the one or more services for preemption based first on the list, second on a common path between the ingress link and the egress link, and third based on characteristics of the one or more services for preemption.

6. The method of claim **1**, wherein the network utilizes one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller.

7. The method of claim 1, wherein the node and each intermediate node in the network for the service are configured to perform the selecting, and wherein the list is utilized to select previously selected services to minimize disruption in the network.

8. A node in a network configured to perform service preemption selection, the node comprising:

a first port coupled to an ingress link, wherein the first port is configured to receive a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request comprises a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link;

a controller configured to select, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria; and

a second port configured to forward the request on an egress link to an adjacent node with any updates based on the one or more services for preemption,

wherein the network utilizes a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller, and wherein the SDN controller provides suggestions for how the controller selects the one or more services for preemption.

9. The node of claim 8, wherein the one or more services for preemption are selected with the list comprising a backward view of the previously selected services for preemption and a limited forward view where the node performs the selecting based in part on the egress link.

10. The node of claim 8, wherein the controller is further configured to determine whether preemption is required on the egress link, and if required, providing an indication of whether preemption is required on the egress link when the second port forwards the request on the egress link.

11. The node of claim 8, wherein the updates comprise addition of the one or more services for preemption in the request.

12. The node of claim 8, wherein the service selection criteria is a hierarchical approach for determining the one or more services for preemption based first on the list, second on a common path between the ingress link and the egress link, and third based on characteristics of the one or more services for preemption.

13. The node of claim 8, wherein the network utilizes one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller.

14. The node of claim 8, wherein the node and each intermediate node in the network for the service are configured to perform the preemption, and wherein the list is utilized to select previously selected services to minimize disruption in the network.

15. A network configured to perform service preemption selection by one or more nodes, the network comprising:

a plurality of nodes interconnected to one another by a plurality of links;

wherein an intermediate node is configured to

receive, from an ingress link, a request to establish a service on a path in the network while preempting one or more existing services if required to establish the service, wherein the request comprises a list of any previously selected services for preemption and an indication of whether preemption is required on the ingress link,

select, if required based on the indication, one or more services for preemption on the ingress link based on service selection criteria, and

forward the request on an egress link to an adjacent node with any updates based on the selecting,

wherein the network utilizes a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller, and wherein the SDN controller provides suggestions for how the controller selects the one or more services for preemption.

16. The network of claim 15, wherein the one or more services for preemption are selected with the list comprising a backward view of the previously selected services for preemption and a limited forward view where the intermediate node performs the selecting based in part on the egress link.

17. The network of claim 15, wherein the intermediate node is configured to determine whether preemption is required on the egress link, and if required, provide an indication of whether preemption is required on the egress link when forwarding to the adjacent node and an indication of any service preempted on the ingress link.

18. The network of claim 15, wherein the network utilizes one of (i) a distributed control plane and (ii) a hybrid control mode with both a control plane and a Software Defined Networking (SDN) controller.

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