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(54) CONFIGURING OPTICAL NETWORKS USING A JOINT CONFIGURATION MODEL

KONFIGURATION VON OPTISCHEN NETZWERKEN UNTER VERWENDUNG EINES GEMEINSAMEN KONFIGURATIONSMODELLS

CONFIGURATION DE RÉSEAUX OPTIQUES À L'AIDE D'UN MODÈLE DE CONFIGURATION CONJOINTE

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Description

Technical Field

[0001] The present disclosure is related to configuring optical networks, and in particular to using a joint configuration model to configure diverse optical networks to form an optical path.

Background

[0002] Optical networks may involve the use of different types of nodes, such as wavelength switched optical networks (WSON) nodes and newer, higher bandwidth flexible grid (Flexi-Grid) nodes. The different types of nodes utilize different configurations and methods of describing channel parameters, such as frequencies and channel separation frequencies.
CHANNEGOWDA MAYUR ET AL: "Software-defined optical networks technology and infrastructure: Enabling software-defined optical network operations [invited]" discloses Software-defined networking (SDN) enables programmable SDN control and management functions at a number of layers, allowing applications to control network resources or information across different technology domains, e.g., Ethernet, wireless, and optical. LOPEZ DE VERGARA UNIVERSIDAD AUTONOMA DE MADRID V LOPEZ O GONZALEZ DEDIOS TELEFONICA I+D/GCTO D KING OLD DOG CONSULTING Z ALI J E: "A YANG data model for WSON and FlexiGrid Optical Networks; draft-vergara-flexigrid-yang-00.txt" defines a YANG model for managing dynamic Optical networks, including Wavelength Switched Optical Networks (WSON) and Flexi-Grid DWDM Networks. The model described in this document is composed of two submodels: one to define an optical traffic engineering database, and other one to describe the optical paths or media channels. "Spectral grids for WDM applications: DWDM frequency grid; G.694.1 (02/12)" provides the definition of a frequency grid to support dense wavelength division multiplexing (DWDM) applications.

Summary

[0003] The invention is defined by the independent claims. Further embodiments of the invention are defined by the dependent claims. Although the invention is only defined by the claims, the below embodiments, examples and aspects are present for aiding in understanding the background and advantages of the invention.

Brief Description of the Drawings

[0004]

FIG. 1 is a block diagram of an optical network showing an optical path extending between a source and a destination according to an example embodiment.

FIG. 2A is a flowchart illustrating a method for establishing an optical path in a network of different types of nodes according to an example embodiment.

FIG. 2B is pseudocode for a joint YANG (Yet Another Next Generation) model for configuring controller nodes in an optical network according to an example embodiment.

FIGs. 3A and 3B are a commented representation of a container representing the YANG model of FIG. 2 according to an example embodiment.

FIG. 4 is a block diagram of an optical network showing an optical path extending between a source and a destination according to an example embodiment.

FIG. 5 is a block diagram of an alternative optical network showing an optical path extending between a source and a destination according to an example embodiment.

FIG. 6A is a block diagram of a further alternative optical network showing an optical path extending between a source and a destination according to an example embodiment.

FIG. 6B is a flowchart illustrating a method to configure different type nodes for data plane based operation according to an example embodiment.

FIG. 7 is a block diagram of an optical network showing yet a further alternative optical path extending between a source and a destination according to an example embodiment.

FIG. 8 is a diagram showing configuration message flow for configuring an optical path or tunnel via a first type of control node in an optical network according to an example embodiment.

FIG. 9 is a diagram showing configuration message flow for configuring an optical path or tunnel via a second type of control node in an optical network according to an example embodiment.

FIG. 10 is a diagram showing configuration message flow for configuring an optical path or tunnel via a diverse set of control nodes in an optical network according to an example embodiment.

FIG. 11 is a flowchart illustrating a computer implemented method of configuring an optical network according to an example embodiment.

FIG. 12 is a flowchart illustrating operations for performing a method of configuring an optical network having mixed nodes while using a single joint configuration model.

FIG. 13 is a block diagram illustrating circuitry for clients, servers, cloud based resources for implementing algorithms and performing methods according to example embodiments.

Detailed Description

[0005] In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

[0006] The functions or algorithms described herein may be implemented in software in one embodiment. The software may consist of computer executable instructions stored on computer readable media or computer readable storage device such as one or more non-transitory memories or other type of hardware based storage devices, either local or networked. Further, such functions correspond to modules, which may be software, hardware, firmware or any combination thereof. Multiple functions may be performed in one or more modules as desired, and the embodiments described are merely examples. The software may be executed on a digital signal processor, ASIC, microprocessor, or other type of processor operating on a computer system, such as a personal computer, server or other computer system, turning such computer system into a specifically programmed machine.

[0007] Optical networks may involve the use of different types of nodes along an optical path between a source and destination, such as WSON nodes and newer, higher bandwidth Flexi-Grid nodes. Nodes in an optical network may be capable of one or more of switching optical signals and regeneration of optical signals. The optical path may be bidirectional or unidirectional.

[0008] The different types of nodes utilize different configurations and methods of describing channel parameters, such as frequencies and channel separation frequencies. Optical network controllers configure the nodes using different configuration models for each type of node to establish one or more optical paths.

[0009] When optical networks are mixed with Fixed-Grid (WSON) and Flexible-Grid (Flexi-Grid) nodes, both types of nodes need to be supported to properly configure an optical path in the network.

[0010] During migration of an optical network from older type nodes to newer nodes, a control plane mechanism used to configure the nodes for providing an optical path for communications has to change when an older node is replaced with a newer node. Changing the mechanism for each replaced node becomes time consuming and subject to error, adding expense to the migration.

[0011] Various aspects of the inventive subject matter facilitate the use of a joint configuration model by a controller, referred to as a provisioning network controller (PNC) to control both WSON and Flexi-Grid nodes to configure an optical path. The PNC does not need to change the configuration model when WSON networks migrate to Flexi-Grid networks, allowing for easier migration.

[0012] A multi-domain controller, referred to as a multi-domain service coordinator (MDSC) may use one configuration interface to each homogenous or heterogeneous PNC, such as one or more PNCs that control domains having WSON nodes, PNCs that control domains having Flexi-Grid nodes, and PNCs that control domains having mixed nodes, such as one or more WSON nodes and Flexi-Grid nodes. In further embodiments, the configuration model may be modified to support more types of nodes with similar advantages.

[0013] FIG. 1 is a block diagram of an optical network 100 showing an optical path 110 extending between a source 115 and a destination 120. The optical path 110 traverses through a first node 125 and a second node 130, both of which are configured by a controller, PNC 135, to establish the optical path. The first and second nodes 125, 130 may be different. In one example embodiment, the first node 125 is a WSON node, and the second node is a newer, higher bandwidth Flexi-Grid node 130. Both such nodes have different data plane capabilities and are controlled differently in order to configure the single optical path 110. A WSON node may perform switching selectively based on a center wavelength of an optical signal and has a fixed 50Ghz slot width. Flexi-grid nodes perform switching based on a center wavelength but with variable size slot width.

[0014] PNC 135 utilizes a joint configuration model 140 in order to control the nodes 125 and 130 via connections 145 and 150, respectively, and configure them for data plane based operations. Configuration model 140 may be used to configure first node 125 by specifying, for example, a selected frequency of 193.1 (THz) and a channel spacing of 50 (GHz). For the sample optical path 110, configuration model 140 may be used by PNC 135 to configure second node 130 by setting N = 0 (f=193.1 THz + Nx000625 THz = 193.1 THz), and, M = 4 (width = M $\times$ 12.5 GHz = 50 GHz). The configuration model 140 may be stored and accessed within PNC 135, or stored and accessed remote from PNC 135 in various embodiments. The difference in configuring the two nodes is that the second node 130 is a Flexi-Grid node, which has a higher bandwidth capability, both in terms of selected frequency, with a base frequency of 193.1 THz and a more granular channel spacing capability. Flexi-Grid nodes are able to fit four channels into a same frequency range as a WSON node.

[0015] FIG. 2A is a flowchart illustrating a method 270 for establishing an optical path in a network of different types of nodes. At operation 275, path frequency and channel spacing are specified for a WSON read and write optical path. At operation 278, the same path frequency and channel spacing are specified for a Flexi-Grid optical path using a different nomenclature that is compatible with Flexi-Grid nodes.

[0016] At operation 280, source and destination are established, along with wavelength parameters. The established parameter, referred to as the state of the path are then read at operation 283 from the nodes in the path. The read parameters are verified at operation 285 to ensure the path was properly established. At operation 288, the path is labeled with the parameters, and at operation 290, constraints of the path, if any, are identified.

[0017] In one embodiment, the configuration model may be expressed as an Internet Engineering Task Force (IETF) YANG tree as shown in pseudocode in FIG. 2 at YANG model 200 describing operations for establishing an optical path (te:tunnel (traffic engineered tunnel)), referred to in the pseudocode as a module named ietf-te-L0 at 202. Operation 204 describes that language from an already established model compiled YANG model is being borrowed for use in YANG model 200 and begins configuration (config) of nodes in the path. Operation 206 is used to describe that the path to be established is a read/write (rw) te L0 slot, while line 208 indicates that the following operations are for WSON nodes, identifying the channel frequency at 210 as a 64 bit decimal format and channel spacing at 212 as a 64 bit decimal format. A te L0 slot is a traffic engineering slot with L0 being a container of YANG to describe Layer 0 Slot of the tunnel between nodes to be configured.

[0018] Operation 214 is used to identify that following operations are for Flexi-Grid nodes and identify parameter N as a 32 bit integer at 216 and M as a 32 bit integer at 218. For one example optical path 110, N = 0 (f=193.1 THz + Nx000625 THz = 193.1 THz), and, M = 4 (width = M $\times$ 12.5 GHz = 50 GHz). Operations 220 and 222 define the source client signal and destination client signal. Operation 224 describes the wavelength assignment for the path.

[0019] Operation 226 causes a read of what was configured, the state of the path. Operations 228, 230, 232, 234, 236, 238, 240, 242, 244, and 246 have a similar format to the above configuration operations 206-224, and serve to read values from configured nodes to ensure configuration of WSON and Flexi-Grid nodes was performed properly.

[0020] Operation 248 is used to label a switched path (lsp) corresponding to the optical path through multiple nodes in the optical network. Operation 250 indicates whether the path is bidirectional or unidirectional and is a Boolean value. Note that the while YANG model 200 uses specified numbers of bits or types of values, different numbers of bits or types of values may be used in other embodiments. Operations 252, 254, 256, 258, 260, 262, and 264 are similar to the above sets of operations and describe the selected channel frequency and spacing for the WSON and Flexi-Grid nodes.

[0021] Operation 266 is used to identify constraints, such as shown at operation 268 wherein an rw wavelength assignment is identified. The assignment may be set via random assignment as show, or globally, which allows direct identification of the wavelength to allow tailoring for a specific instance of a path.

[0022] FIGs. 3A and 3B are a commented representation of a container: L0-slot that illustrates the YANG model of FIG. 2 shown generally at 300. A grouping of tunnel properties is illustrated at 310 where configuration parameters relating to TE L0 Tunnel attributes are specified.

[0023] A choice at 320 allows the selection of technology specifics, such as the WSON case 325 and the Flexi-Grid case 330. WSON case 325 includes the configuration parameters relating to TE WSON Tunnel attribute flags, such as leaf (channel) selected frequency, type, units of THz, default channel frequency 193.1 THz, and leaf channel spacing which is 12.5 GHz for WSON nodes.

[0024] Case 330 shows technology specifics of Flexi-Grid nodes, such as configuration parameters N and M. For Flexi-Grid nodes, N is used to determine the Nominal Central Frequency. The set of nominal central frequencies can be built using the following expression: f = 193.1 THz + n $\times$ 0.00625 THz, where 193.1 THz is ITU-T "anchor frequency" for transmission over the C band, and n is a positive or negative integer including 0. M is used to determine the slot width. A slot width is constrained to be M $\times$ SWG (slot width grid) (that is, M $\times$ 12.5 GHz), where M is an integer greater than or equal to 1. Note that even further different types of nodes may be similarly calculated once the frequency and channel spacing is specified for any one of the types of nodes in the format utilized for such type of node.

[0025] FIG. 4 is a block diagram of an optical network 400 showing an optical path 410 extending between a source 115 and a destination 120. Note that reference numbers are used for like components in each of the optical network figures. Each of the optical network figures show only the nodes and controllers used for establishing an optical path. The optical networks may consist of many other nodes and optical connections that are not used for the illustrated optical path and are not shown for convenience of illustration.

[0026] The optical path 410 traverses through two WSON nodes 125, both of which are configured by a controller, PNC 135, to establish the optical path. Both nodes have the same data plane capabilities.

[0027] PNC 135 utilizes the joint configuration model 140 in order to control the nodes via connections 145 and configure them for data plane based operation. Configuration model 140 may be used to configure both nodes 125 by specifying, for example, a selected frequency of 193.1 (THz) and a channel spacing of 50 (GHz).

[0028] FIG. 5 is a block diagram of an optical network 500 showing an optical path 510 extending between a source 115 and a destination 120. The optical path 510 traverses through a pair of nodes 130, both of which are configured by a controller, PNC 135, to establish the optical path. Nodes 130 are both Flexi-Grid nodes.

[0029] PNC 135 utilizes a joint configuration model 140 in order to control the nodes via connections 150 and configure them for data plane based operation. Configuration model 140 may be used to configure nodes 130 by setting N = 0 (f= 193.1 THz + N $\times$ 000625 THz = 193.1 THz), and, M = 4 (width = M $\times$ 12.5 GHz = 50 GHz). In one embodiment, the nodes 130 may have been upgraded or migrated from WSON nodes as shown in FIG. 4. The use of a joint configuration model for multiple types of nodes allows such migration without having to modify the configuration model during the migration.

[0030] FIG. 6A is a block diagram of an optical network 600 showing an optical path 610 extending between a source 115 and a destination 120. The optical path 610 traverses through multiple pairs of nodes 125 and 130, which are configured by a pair of controllers, both shown as PNC 135, to establish the optical path. Nodes 125 are both WSON nodes in a domain controlled by one PNC 135 while nodes 130 are both Flexi-Grid nodes in a domain controlled by another PNC 135.

[0031] PNC 135 utilizes a joint configuration model 140 in order to control the nodes via connections 150 and configure them for data plane based operation as described above. A controller, such as a multiple domain service coordinator (MDSC) 605 is used to control both PNCs 135 via one configuration interface as indicated by connections 615 and 620. Such control may be done without regard to the different types of nodes in the different domains.

[0032] FIG. 6B is a flowchart illustrating a method 630 of controlling nodes via the connections 150 to configure them for data plane based operation. At operation 635, each PNC 135 will receive control information from MDSC 605, such as frequency and channel spacing information in a single format and convert such control information using the configuration model 140 as indicated at operation 640. At operation 645, the PNC 135 coupled to the WSON nodes 125 configures the WSON nodes 125 with the proper frequency and channel spacing. Responsive to operation 640, the PNC 135 coupled to the Flexi-Grid nodes 130 configures the Flexi-Grid nodes with the converted control information to operate at the same frequency and channel spacing. MDSC 605 also selects and coordinates the PNCs to establish the tunnel, i.e., the optical path 610.

[0033] In one embodiment, the nodes 130 may have been upgraded or migrated from WSON nodes. The use of a joint configuration model 140 for multiple types of nodes 125, 130 allows such migration without having to modify the configuration model during the migration. Migration of the entire optical network may occur over time, without having to upgrade the entire network at the same time and without having to change the joint configuration model during that time.

[0034] FIG. 7 is a block diagram of an optical network 700 showing an optical path 710 extending between a source 115 and a destination 120. The optical path 710 traverses through multiple nodes 125 and 130 in different, mixed node domains. The nodes are all configured by a PNCs 135, to establish the optical path. Domains with mixed nodes, both WSON nodes and Flexi-Grid nodes are each controlled by a PNC 135. Method 635 may be executed by each PNC 135 to configure their respective WSON node and Flexi-Grid node.

[0035] PNC 135 utilizes a joint configuration model 140 (not shown here) in order to control the nodes via connections 145 and 150 and configure them for data plane based operation as described above. An MDSC 605 is used to control both PNCs 135 via one configuration interface as indicated by connections 615 and 620. Such control may be done without regard to the different types of nodes in the different domains. Each PNC 135 will receive control information from MDSC 605, such as frequency and channel spacing information in a single format and convert such control information using the configuration model 140. MDSC 605 also selects and coordinates the PNCs to establish the tunnel, i.e., the optical path 610.

[0036] FIG. 8 is a diagram showing configuration message flow 800 for configuring an optical path or tunnel in an optical network. Flow 800 establishes a LOTE-tunnel (Layer zero, traffic engineered-tunnel), at one or more WSON nodes 125 by one or more PNCs 135 in one embodiment, but other types of optical paths may be established in a similar manner. A first control request 810, POST/tunnels/tunnel/L0TE-tunnel is a communication sent from PNC 135 to WSON node 125 to establish tunnel or optical path. WSON node 125 processes the command and returns a confirmation 820 of HTTP 200: Tunnel, confirming that the tunnel has been established. POST is an HTTP (hyper text transfer protocol) message that tells the receiver to "configure" the optical path. In this case, the message informs the receiver to configure the optical path based on YANG model container called tunnels/tunnel/L0TE-tunnel. HTTP 200 is a status code indicating that the request has succeeded. A POST is a request in HTTP.

[0037] FIG. 9 dis a diagram showing configuration message flow 900 for configuring an optical path or tunnel in an optical network. Flow 900 establishes a LOTE-tunnel at one or more Flexi-Grid nodes 130 by one or more PNCs 135 in one embodiment, but other types of optical paths may be established in a similar manner. A first control command 910, POST/tunnels/tunnel/L0TE-tunnel is sent from PNC 135 to Flexi-Grid node 130, which processes the command and returns a confirmation 920 of HTTP 200: Tunnel, confirming that the tunnel has been established.

[0038] FIG. 10 is a diagram showing configuration message flow 1000 for configuring an optical path or tunnel in an optical network having a diverse mix of nodes, such as WSON nodes 125 and Flexi-Grid nodes 135. Flow 1000 establishes a LOTE-tunnel at one or more nodes 125, 130 by one or more PNCs 135 in one embodiment. An MDSC 605 is used to establish the optical path over multiple domains controlled by multiple PNCs 135. Two POST requests 1010 and 1020 are used for respective PNCs 135. Both PNCs send POST requests 810 and 910 to respective types of nodes and receive confirmations 820 and 920 as described with respect to FIGs. 8 and 9. Each PNC 135 for the different domains forward the respective confirmations 1030 and 1040 back to the MDSC to establish the tunnel/optical path. While only two PNCs 135 and nodes 125, 130 are shown, it should be understood that there may be many more such PNCs and nodes involved in the path, and that such domains may each have mixed nodes or homogenous nodes - nodes of the same type.

[0039] FIG. 11 is a flowchart illustrating operations for execution by suitable computing resources, such as a PNC or a node controller in an optical network, to perform an example method 1100 of configuring an optical network having mixed nodes while using a single joint configuration model. Operation 1110 may be performed to select a wavelength for the optical path. The wavelength may be selected randomly or assigned by a multi-domain controller in different embodiments. Operation 1120 may be executed to generate a first request for a first type of node in the optical path. Operation 1130 may be executed to generate a second request for a second type of node in the optical path. The second type of node may have different data plane capabilities than the first type of node. The first and second requests may be generated as a function of the joint configuration model accommodating both types of nodes. Operation 1140 may be performed to send the first request to the first type of node and the second request to the second type of node to configure the optical path at operation 1150.

[0040] In one embodiment the first and second types of nodes have wavelength capabilities that are specified differently in their respective requests. The first and second requests may be generated and sent via a provisioning network controller node in communication with the first and second type nodes. In a further embodiment, the first and second requests may be generated and sent via a multi-domain service coordinator communicatively coupled to heterogeneous provisioning network controller nodes. Each controller node may be in communication with multiple first or second type nodes in the optical path.

[0041] The first type of node may comprise a WSON node and the second type of node may comprise a Flexi-Grid node. The first request may specifies a path frequency and channel spacing of the optical path and the second request specifies the frequency and channel spacing as a function of a multiple of slot widths of the Flexi-Grid node to match the channel spacing specified for the WSON node.

[0042] The first request for the WSON directly specifies the path frequency f_p and channel spacing f_{cs}, and the second request for the Flexi-Grid node specifies the same path frequency as ($f_p = f_p + n \times 0.00625$) where n = 0, and channel spacing as ($f_{cs} = M \times 12.5$) where M = 4. The joint configuration model may be in the form of a compiled YANG tree.

[0043] FIG. 12 is a flowchart illustrating operations for execution by suitable computing resources, such as a PNC or node controller in an optical network, to perform an example method 1200 of configuring an optical network having mixed nodes while using a single joint configuration model. At operation 1210, a channel wavelength for an optical path may be obtained. Obtaining such a wavelength may be performed by receiving the wavelength from another controller or generating it randomly responsive to a request for an optical path. Operation 1220 determines a type of node in the optical path.

[0044] Operation 1230 involves executing a mixed node configuration model to determine how to control the type of node. The mixed node configuration model is used for configuring multiple different types of nodes which each have different control plane capabilities and may differ in the way channel parameters are specified to control the type of node coupled to the controller. The configuration plane determines, based on the node type, how to specify the channel parameters. At operation 1240, a configuration request is sent to the node in accordance with the configuration model, and at operation 1250, a response may be received from the node, confirming the request.

[0045] The method 1200 may be used multiple times by one or more controllers which may be controlling different domains of nodes in a large optical network. The use of a joint configuration file enables configuration of mixed nodes throughout the domains without having to ensure each controller has a different or multiple different configuration files for each of the types of nodes in their respective domains.

[0046] FIG. 13 is a block diagram illustrating circuitry/programming resources for using a joint configuration model for configuring mixed nodes in an optical network to establish a tunnel/optical path through the network regardless of the use of different types of nodes in the resulting path and for performing methods according to example embodiments. All components need not be used in various embodiments.

[0047] One example computing device in the form of a computer 1300 may include a processing unit 1302, memory 1303, removable storage 1310, and non-removable storage 1312. Although the example computing device is illustrated and described as computer 1300, the computing device may be in different forms in different embodiments. For example, the computing device may instead be a smartphone, a tablet, smartwatch, controller, or other computing device including the same or similar elements as illustrated and described with regard to FIG. 13. Devices, such as smartphones, tablets, and smartwatches, are generally collectively referred to as mobile devices or user equipment. Further, although the various data storage elements are illustrated as part of the computer 1300, the storage may also or alternatively include cloud-based storage accessible via a network, such as the Internet or server based storage.

[0048] Memory 1303 may include volatile memory 1314 and non-volatile memory 1308. Computer 1300 may include - or have access to a computing environment that includes - a variety of computer-readable media, such as volatile memory 1314 and non-volatile memory 1308, removable storage 1310 and non-removable storage 1312. Computer storage includes random access memory (RAM), read only memory (ROM), erasable programmable read-only memory (EPROM) or electrically erasable programmable read-only memory (EEPROM), flash memory or other memory technologies, compact disc read-only memory (CD ROM), Digital Versatile Disks (DVD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium capable of storing computer-readable instructions.

[0049] Computer 1300 may include or have access to a computing environment that includes input interface 1306, output interface 1304, and a communication interface 1316. Output interface 1304 may include a display device, such as a touchscreen, that also may serve as an input device. The input interface 1306 may include one or more of a touchscreen, touchpad, mouse, keyboard, camera, one or more device-specific buttons, one or more sensors integrated within or coupled via wired or wireless data connections to the computer 1300, and other input devices. The computer may operate in a networked environment using a communication connection to connect to one or more remote computers, such as database servers. The remote computer may include a personal computer (PC), server, router, network PC, a peer device or other common DFD network switch, or the like.

[0050] In one embodiment, A computer device capable of configuring an optical path includes a selecting means for selecting a wavelength for the optical path and generating means for generating a first request for a first type of node in the optical path and a second request for a second type of node in the optical path, the second type of node having different data plane capabilities than the first type of node, wherein the first and second requests are generated as a function of a joint configuration model accommodating both types of nodes. The computer device further includes sending means for sending the first request from the one or more processors to the first type of node and the second request to the second type of node to configure the optical path.

[0051] The communication connection may include a Local Area Network (LAN), a Wide Area Network (WAN), cellular, WiFi, Bluetooth, optical, or other networks. According to one embodiment, the various components of computer 1300 are connected with a system bus 1320.

[0052] Computer-readable instructions stored on a computer-readable medium are executable by the processing unit 1302 of the computer 1300, such as a program 1318. The program 1318 in some examples comprises software that, when executed by the processing unit 1302, performs node configuration operations according to any of the examples included herein. A hard drive, CD-ROM, and RAM are some examples of articles including a non-transitory computer-readable medium such as a storage device. The terms computer-readable medium and storage device do not include carrier waves to the extent carrier waves are deemed too transitory. Storage can also include networked storage, such as a storage area network (SAN). Computer program 1318 may be used to cause processing unit 1302 to perform one or more methods or algorithms described herein.

[0053] Although a few embodiments have been described in detail above, other modifications are possible, as long as they do not depart from the scope of the invention as it is depicted by the appended claims.

Claims

1. A computer implemented method of configuring an optical path, wherein the method is implemented by a node controller, and the method comprising:

selecting (1110) with one or more processors a wavelength for the optical path;
generating (1120) with one or more processors, a first request for a first type of node (125) in the optical path;
generating (1130) with one or more processors a second request for a second type of node (130) in the optical path, the first type of node and the second type of node in different domains and having different data plane capabilities, wherein the first and second requests are generated as a function of a joint configuration model (140) accommodating both types of nodes, the joint configuration model comprises a Yet Another Next Generation, YANG, model describing operations for establishing the optical path, and the joint configuration model is used to convert a central frequency and channel spacing in a single format to the same central frequency and channel spacing in a different nomenclature for the first type of node and the second type of node; and
sending (1140) the first request from the one or more processors to the first type of node and the second request to the second type of node to configure the optical path.

2. The method of claim 1, wherein the first and second types of nodes have wavelength data plane capabilities that are specified differently in their respective requests.

3. The method of any one of claims 1-2, wherein the first and second requests are generated and sent via one or more processors of a provisioning network controller node in communication with the first and second types of nodes.

4. The method of any one of claims 1-3, wherein the first and second requests are generated responsive to a multi-domain service coordinator having one or more processors communicatively coupled to heterogeneous provisioning network controller nodes, each controller node in communication with multiple first or second type nodes in the optical path.

5. The method of any one of claims 1-4, wherein the first type of node comprises a wavelength switched optical network, WSON, node and the second type of node comprises a Flexi-Grid node.

6. The method of any one of claims 1-5, wherein the first request specifies the central frequency and channel spacing of the optical path and the second request specifies the central frequency and channel spacing as a function of a multiple of slot widths of the Flexi-Grid node to match the channel spacing specified for the WSON node.

7. The method of any one of claims 1-6, wherein the first request for the WSON directly specifies the central frequency, f_p, and channel spacing, f_{cs}, and the second request for the Flexi-Grid node specifies the central frequency as $f_{p =} f_p + n \times 0.00625$, where n = 0, and channel spacing as $f_{cs} = M \times 12.5$, where M = 4.

8. The method of any one of claims 1-7, wherein the joint configuration model comprises a compiled YANG tree.

9. An optical network node controller (135) comprising:

a memory storage comprising instructions; and one or more processors in communication with the memory storage, wherein the one or more processor execute the instructions to perform operations comprising:

selecting (1110) with one or more processors a wavelength for an optical path;
generating (1120) with one or more processors, a first request for a first type of node (125) in the optical path;
generating (1130) with one or more processors a second request for a second type of node (130) in the optical path, the first type of node and the second type of node in different domains and having different data plane capabilities, wherein the first and second requests are generated as a function of a joint configuration model (140) accommodating both types of nodes, the joint configuration model comprises a Yet Another Next Generation, YANG, model describing operations for establishing the optical path, and the joint configuration model is used to convert a central frequency and channel spacing in a single format to the same central frequency and channel spacing in a different nomenclature for the first type of node and the second type of node; and
sending the first request from the one or more processors to the first type of node and the second request to the second type of node to configure the optical path.

10. The optical network node controller of claim 9, wherein the first and second requests are generated responsive to a multi-domain service coordinator having one or more processors communicatively coupled to heterogeneous provisioning network controller nodes, each controller node in communication with multiple first or second type nodes in the optical path.

11. The optical network node controller of any one of claims 9-10, wherein the first type of node comprises a wavelength switched optical network, WSON, node and the second type of node comprises a Flexi-Grid node.

12. The optical network node controller of any one of claims 9-11, wherein the first request specifies the central frequency and channel spacing of the optical path and the second request specifies the central frequency and channel spacing as a function of a multiple of slot widths of the Flexi-Grid node to match the channel spacing specified for the WSON node.

13. The optical network node controller of any one of claims 9-12, wherein the first request for the WSON directly specifies the central frequency, f_p, and channel spacing, f_{cs}, and the second request for the Flexi-Grid node specifies the central frequency as $f_{p =} f_p + n \times 0.00625$, where n = 0, and channel spacing as $f_{cs} = M \times 12.5$, where M = 4.

14. A non-transitory computer-readable media storing computer instructions for configuring nodes in an optical network, that when executed by one or more processors, cause the one or more processors to perform steps of

selecting (1110) with one or more processors a wavelength for an optical path;
generating (1120) with one or more processors, a first request for a first type of node (125) in the optical path;
generating (1130) with one or more processors a second request for a second type of node (130) in the optical path, the first type of node and the second type of node in different domains and having different data plane capabilities, wherein the first and second requests are generated as a function of a joint configuration model (140) accommodating both types of nodes, the joint configuration model comprises a Yet Another Next Generation, YANG, model describing op-

erations for establishing the optical path, and the joint configuration model is used to convert a central frequency and channel spacing in a single format to the same central frequency and channel spacing in a different nomenclature for the first type of node and the second type of node; and
sending (1140) the first request from the one or more processors to the first type of node and the second request to the second type of node to configure the optical path.

15. The non-transitory computer-readable media of claim 14, wherein the first and second types of nodes have wavelength data plane capabilities that are specified differently in their respective requests.

Patentansprüche

1. Computerimplementiertes Verfahren zum Konfigurieren eines Strahlengangs, wobei das Verfahren durch eine Knotensteuerung implementiert ist und das Verfahren umfasst:

Auswählen (1110), mit einem oder mehreren Prozessoren, einer Wellenlänge für den Strahlengang;
Erzeugen (1120), mit einem oder mehreren Prozessoren, einer ersten Anforderung für einen ersten Typ von Knoten (125) in dem Strahlengang;
Erzeugen (1130), mit einem oder mehreren Prozessoren, einer zweiten Anforderung für einen zweiten Typ von Knoten (130) in dem Strahlengang, wobei der erste Typ von Knoten und der zweite Typ von Knoten in unterschiedlichen Domänen und
unterschiedliche Datenebenenfähigkeiten aufweisen, wobei die erste und die zweite Anforderung in Abhängigkeit von einem gemeinsamen Konfigurationsmodell (140) erzeugt werden, das beide Typen von Knoten aufnimmt, wobei das gemeinsame Konfigurationsmodell ein Yet Another Next Generation-Modell, YANG-Modell, das Vorgänge zum Einrichten des Strahlengangs beschreibt, umfasst, und das gemeinsame Konfigurationsmodell verwendet wird, um eine zentrale Frequenz und einen Kanalabstand in einem einzelnen Format in die gleiche zentrale Frequenz und den Kanalabstand in einer unterschiedlichen Nomenklatur für den ersten Typ von Knoten und den zweiten Typ von Knoten umzuwandeln; und
Senden (1140) der ersten Anforderung von dem einen oder den mehreren Prozessoren an den ersten Typ von Knoten und der zweiten Anforderung an den zweiten Typ von Knoten, um den Strahlengang zu konfigurieren.

2. Verfahren nach Anspruch 1, wobei der erste und der zweite Typ von Knoten Wellenlängendatenebenenfähigkeiten aufweisen, die in ihren jeweiligen Anforderungen unterschiedlich spezifiziert sind.

3. Verfahren nach einem der Ansprüche 1 bis 2, wobei die erste und die zweite Anforderung über einen oder mehrere Prozessoren eines Bereitstellungsnetzwerksteuerungsknotens in Kommunikation mit dem ersten und dem zweiten Typ von Knoten erzeugt und gesendet werden.

4. Verfahren nach einem der Ansprüche 1 bis 3, wobei die erste und die zweite Anforderung als Reaktion auf einen Mehrdomänen-Dienstkoordinator, der einen oder mehrere Prozessoren aufweist, die kommunikativ mit heterogenen Bereitstellungsnetzwerksteuerungsknoten gekoppelt sind, erzeugt werden, wobei jeder Steuerungsknoten in Kommunikation mit mehreren ersten oder zweiten Knotentypen in dem Strahlengang.

5. Verfahren nach einem der Ansprüche 1 bis 4, wobei der erste Typ von Knoten einen Knoten eines wellenlängengeschalteten optischen Netzwerks, WSON-Knoten, umfasst, und der zweite Typ von Knoten einen Flexi-Gitter-Knoten umfasst.

6. Verfahren nach einem der Ansprüche 1 bis 5, wobei die erste Anforderung die zentrale Frequenz und den Kanalabstand des Strahlengangs spezifiziert und die zweite Anforderung die zentrale Frequenz und den Kanalabstand in Abhängigkeit von mehreren Schlitzbreiten des Flexi-Gitter-Knotens angibt, um den für das WSON-Knoten spezifizierten Kanalabstand anzupassen.

7. Verfahren nach einem der Ansprüche 1 bis 6, wobei die erste Anforderung für das WSON direkt die zentrale Frequenz, f_p, und den Kanalabstand, f_{cs}, spezifiziert und die zweite Anforderung für den Flexi-Gitter-Knoten die zentrale Frequenz als $f_p = f_p + n \times 0{,}00625$, wobei n = 0 ist, und den Kanalabstand als $f_{cs} = M \times 12{,}5$, wobei M = 4 ist, spezifiziert.

8. Verfahren nach einem der Ansprüche 1 bis 7, wobei das gemeinsame Konfigurationsmodell einen kompilierten YANG-Baum umfasst.

9. Optische Netzwerkknotensteuerung (135), die umfasst:

einen Speicher, der Anweisungen umfasst; und
einen oder mehrere Prozessoren in Kommunikation mit der Speicherspeicherung,
wobei der eine oder die mehreren Prozessoren

die Anweisungen ausführen, um Vorgänge durchzuführen, die umfassen:

Auswählen (1110), mit einem oder mehreren Prozessoren, einer Wellenlänge für einen Strahlengang;
Erzeugen (1120), mit einem oder mehreren Prozessoren, einer ersten Anforderung für einen ersten Typ von Knoten (125) in dem Strahlengang;
Erzeugen (1130), mit einem oder mehreren Prozessoren, einer zweiten Anforderung für einen zweiten Typ von Knoten (130) in dem Strahlengang, wobei der erste Typ von Knoten und der zweite Typ von Knoten in unterschiedlichen Domänen und unterschiedliche Datenebenenfähigkeiten aufweisen, wobei die erste und die zweite Anforderung in Abhängigkeit von einem gemeinsamen Konfigurationsmodell (140) erzeugt werden, das beide Typen von Knoten aufnimmt, wobei das gemeinsame Konfigurationsmodell ein Yet Another Next Generation-Modell, YANG-Modell, das Vorgänge zum Einrichten des Strahlengangs beschreibt, umfasst, und das gemeinsame Konfigurationsmodell verwendet wird, um eine zentrale Frequenz und einen Kanalabstand in einem einzelnen Format in die gleiche zentrale Frequenz und den Kanalabstand in einer unterschiedlichen Nomenklatur für den ersten Typ von Knoten und den zweiten Typ von Knoten umzuwandeln; und
Senden der ersten Anforderung von dem einen oder den mehreren Prozessoren an den ersten Typ von Knoten und der zweiten Anforderung an den zweiten Typ von Knoten, um den Strahlengang zu konfigurieren.

10. Optische Netzwerkknotensteuerung nach Anspruch 9, wobei die erste und die zweite Anforderung als Reaktion auf einen Mehrdomänen-Dienstkoordinator, der einen oder mehrere Prozessoren aufweist, die kommunikativ mit heterogenen Bereitstellungsnetzwerksteuerungsknoten gekoppelt sind, erzeugt werden, wobei jeder Steuerungsknoten in Kommunikation mit mehreren ersten oder zweiten Knotentypen in dem Strahlengang.

11. Optische Netzwerkknotensteuerung nach einem der Ansprüche 9 bis 10, wobei der erste Typ von Knoten einen Knoten eines wellenlängengeschalteten optischen Netzwerks, WSON-Knoten, umfasst und der zweite Typ von Knoten einen Flexi-Gitter-Knoten umfasst.

12. Optische Netzwerkknotensteuerung nach einem der Ansprüche 9 bis 11, wobei die erste Anforderung die zentrale Frequenz und den Kanalabstand des Strahlengangs angibt und die zweite Anforderung die zentrale Frequenz und den Kanalabstand in Abhängigkeit von mehreren Schlitzbreiten des Flexi-Gitter-Knotens spezifiziert, um den für das WSON-Knoten spezifizierten Kanalabstand anzupassen.

13. Optische Netzwerkknotensteuerung nach einem der Ansprüche 9 bis 12, wobei die erste Anforderung für das WSON direkt die zentrale Frequenz, f_p, und Kanalabstand, f_{cs}, spezifiziert und die zweite Anforderung für den Flexi-Gitter-Knoten die Mittenfrequenz als $f_p = f_p + n \times 0{,}00625$, wobei n = 0 ist, und den Kanalabstand als $f_{cs} = M \times 12{,}5$, wobei M = 4 ist, spezifiziert.

14. Nicht transitorisches computerlesbares Medium, das Computeranweisungen zum Konfigurieren von Knoten in einem optischen Netzwerk speichert, die, wenn sie durch einen oder mehrere Prozessoren ausgeführt werden, den einen oder die mehreren Prozessoren veranlassen, die Schritte durchzuführen Auswählen (1110), mit einem oder mehreren Prozessoren, einer Wellenlänge für einen Strahlengang;

Erzeugen (1120), mit einem oder mehreren Prozessoren, einer ersten Anforderung für einen ersten Typ von Knoten (125) in dem Strahlengang;
Erzeugen (1130), mit einem oder mehreren Prozessoren, einer zweiten Anforderung für einen zweiten Typ von Knoten (130) in dem Strahlengang, wobei der erste Typ von Knoten und der zweite Typ von Knoten in unterschiedlichen Domänen und unterschiedliche Datenebenenfähigkeiten aufweisen, wobei die erste und die zweite Anforderung in Abhängigkeit von einem gemeinsamen Konfigurationsmodell (140) erzeugt werden, das beide Typen von Knoten aufnimmt, wobei das gemeinsame Konfigurationsmodell ein Yet Another Next Generation-Modell, YANG-Modell, das Vorgänge zum Einrichten des Strahlengangs beschreibt, umfasst, und das gemeinsame Konfigurationsmodell verwendet wird, um eine zentrale Frequenz und einen Kanalabstand in einem einzelnen Format in die gleiche zentrale Frequenz und den Kanalabstand in einer unterschiedlichen Nomenklatur für den ersten Typ von Knoten und den zweiten Typ von Knoten umzuwandeln; und
Senden (1140) der ersten Anforderung von dem einen oder den mehreren Prozessoren an den ersten Typ von Knoten und der zweiten Anforderung an den zweiten Typ von Knoten, um den Strahlengang zu konfigurieren.

15. Nicht transitorisches computerlesbares Medium nach Anspruch 14, wobei der erste und der zweite Typ von Knoten Wellenlängendatenebenenfähigkeiten aufweisen, die in ihren jeweiligen Anforderungen unterschiedlich spezifiziert sind.

Revendications

1. Procédé mis en oeuvre par ordinateur de configuration d'un trajet optique, dans lequel le procédé est mis en oeuvre par un contrôleur de noeud, et le procédé comprend :

   la sélection (1110) avec un ou plusieurs processeurs d'une longueur d'onde pour le trajet optique ;
   la génération (1120) avec un ou plusieurs processeurs, d'une première demande pour un premier type de noeud (125) dans le trajet optique ;
   la génération (1130) avec un ou plusieurs processeurs d'une seconde demande pour un second type de noeud (130) dans le trajet optique, le premier type de noeud et le second type de noeud dans différents domaines et ayant des capacités de plan de données différentes, dans lequel les première et seconde demandes sont générées en fonction d'un modèle de configuration conjointe (140) recevant les deux types de noeuds, le modèle de configuration conjointe comprend un modèle de nouvelle génération, YANG, décrivant des opérations pour établir le trajet optique, et le modèle de configuration conjointe est utilisé pour convertir une fréquence centrale et un espacement de canal en un format unique en une même fréquence centrale et espacement de canal dans une nomenclature différente pour le premier type de noeud et le second type de noeud ; et
   l'envoi (1140) de la première demande provenant du ou des processeurs au premier type de noeud et à la seconde demande au second type de noeud pour configurer le trajet optique.

2. Procédé selon la revendication 1, dans lequel les premier et second types de noeuds ont des capacités de plan de données de longueur d'onde qui sont spécifiées différemment dans leurs demandes respectives.

3. Procédé selon l'une quelconque des revendications 1 ou 2, dans lequel les première et seconde demandes sont générées et envoyées par l'intermédiaire d'un ou plusieurs processeurs d'un noeud de contrôleur de réseau de provisionnement en communication avec les premier et second types de noeuds.

4. Procédé selon l'une quelconque des revendications 1 à 3, dans lequel les première et seconde demandes sont générées en réponse à un coordinateur de service multi-domaines ayant un ou plusieurs processeurs couplés en communication à des noeuds de contrôleur de réseau de provisionnement hétérogènes, chaque noeud de contrôleur en communication avec de multiples premier ou second noeuds de type dans le trajet optique.

5. Procédé selon l'une quelconque des revendications 1 à 4, dans lequel le premier type de noeud comprend un noeud de réseau optique commuté par longueur d'onde, WSON, et le second type de noeud comprend un noeud Flexi-Grid.

6. Procédé selon l'une quelconque des revendications 1 à 5, dans lequel la première demande spécifie la fréquence centrale et l'espacement de canal du trajet optique et la seconde demande spécifie la fréquence centrale et l'espacement de canal en fonction d'un multiple de largeurs de créneau du noeud Flexi-Grid pour correspondre à l'espacement de canal spécifié pour le noeud WSON.

7. Procédé selon l'une quelconque des revendications 1 à 6, dans lequel la première demande pour le WSON spécifie directement la fréquence centrale, f_p et l'espacement de canal, f_{cs} et la seconde demande pour le noeud Flexi-Grid spécifie la fréquence centrale en f_p - f_p + n $\times$ 0,00625, où n = 0, et un espacement de canal en tant que f_{cs} = M $\times$ 12,5, où M = 4.

8. Procédé selon l'une quelconque des revendications 1 à 7, dans lequel le modèle de configuration conjointe comprend un arbre YANG compilé.

9. Contrôleur de noeud de réseau optique (135) comprenant :

   un stockage de mémoire comprenant des instructions ; et
   un ou plusieurs processeurs en communication avec le stockage de mémoire, dans lequel le ou les processeurs exécutent les instructions pour effectuer les opérations comprennent :

      la sélection (1110) avec un ou plusieurs processeurs d'une longueur d'onde pour un trajet optique ;
      la génération (1120) avec un ou plusieurs processeurs, d'une première demande pour un premier type de noeud (125) dans le trajet optique ;
      la génération (1130) avec un ou plusieurs processeurs d'une seconde demande pour un second type de noeud (130) dans le trajet optique, le premier type de noeud et le second type de noeud dans différents domai-

nes et ayant des capacités de plan de données différentes, dans lequel les première et seconde demandes sont générées en fonction d'un modèle de configuration conjointe (140) recevant les deux types de noeuds, le modèle de configuration conjointe comprend un modèle de nouvelle génération, YANG, décrivant des opérations pour établir le trajet optique, et le modèle de configuration conjointe est utilisé pour convertir une fréquence centrale et un espacement de canal en un format unique en une même fréquence centrale et espacement de canal dans une nomenclature différente pour le premier type de noeud et le second type de noeud ; et

l'envoi de la première demande du ou des processeurs au premier type de noeud et la seconde demande au second type de noeud pour configurer le trajet optique.

10. Contrôleur de noeud de réseau optique selon la revendication 9, dans lequel les première et seconde demandes sont générées en réponse à un coordinateur de service multi-domaines ayant un ou plusieurs processeurs couplés en communication à des noeuds de contrôleur de réseau de provisionnement hétérogènes, chaque noeud de contrôleur étant en communication avec de multiples premier ou second noeuds de type dans le trajet optique.

11. Contrôleur de noeud de réseau optique selon l'une quelconque des revendications 9 à 10, dans lequel le premier type de noeud comprend un noeud de réseau optique commuté par longueur d'onde, WSON, et le second type de noeud comprend un noeud Flexi-Grid.

12. Contrôleur de noeud de réseau optique selon l'une quelconque des revendications 9 à 11, dans lequel la première demande spécifie la fréquence centrale et l'espacement de canal du trajet optique et la seconde demande spécifie la fréquence centrale et l'espacement de canal en fonction d'un multiple de largeurs de créneau du noeud Flexi-Grid pour correspondre à l'espacement de canal spécifié pour le noeud WSON.

13. Contrôleur de noeud de réseau optique selon l'une quelconque des revendications 9 à 12, dans lequel la première demande pour le WSON spécifie directement la fréquence centrale, f_p et l'espacement de canal, f_{cs} et la seconde demande pour le noeud Flexi-Grid spécifie la fréquence centrale en $f_p = f_p + n \times 0{,}00625$, où n = 0, et un espacement de canal en tant que $f_{cs} = M \times 12{,}5$, où M = 4.

14. Support non transitoire lisible par ordinateur stockant des instructions informatiques pour configurer des noeuds dans un réseau optique qui, lorsqu'elles sont exécutées par un ou plusieurs processeurs, amènent le ou les processeurs à effectuer les étapes consistant à la sélection (1110) avec un ou plusieurs processeurs d'une longueur d'onde pour un trajet optique ;

la génération (1120) avec un ou plusieurs processeurs, d'une première demande pour un premier type de noeud (125) dans le trajet optique ;
la génération (1130) avec un ou plusieurs processeurs d'une seconde demande pour un second type de noeud (130) dans le trajet optique, le premier type de noeud et le second type de noeud dans différents domaines et ayant des capacités de plan de données différentes, dans lequel les première et seconde demandes sont générées en fonction d'un modèle de configuration conjointe (140) recevant les deux types de noeuds, le modèle de configuration conjointe comprend un modèle de nouvelle génération, YANG, décrivant des opérations pour établir le trajet optique, et le modèle de configuration conjointe est utilisé pour convertir une fréquence centrale et un espacement de canal en un format unique en une même fréquence centrale et espacement de canal dans une nomenclature différente pour le premier type de noeud et le second type de noeud ; et
l'envoi (1140) de la première demande provenant du ou des processeurs au premier type de noeud et à la seconde demande au second type de noeud pour configurer le trajet optique.

15. Support non transitoire lisible par ordinateur selon la revendication 14, dans lequel les premier et second types de noeuds ont des capacités de plan de données de longueur d'onde qui sont spécifiées différemment dans leurs demandes respectives.

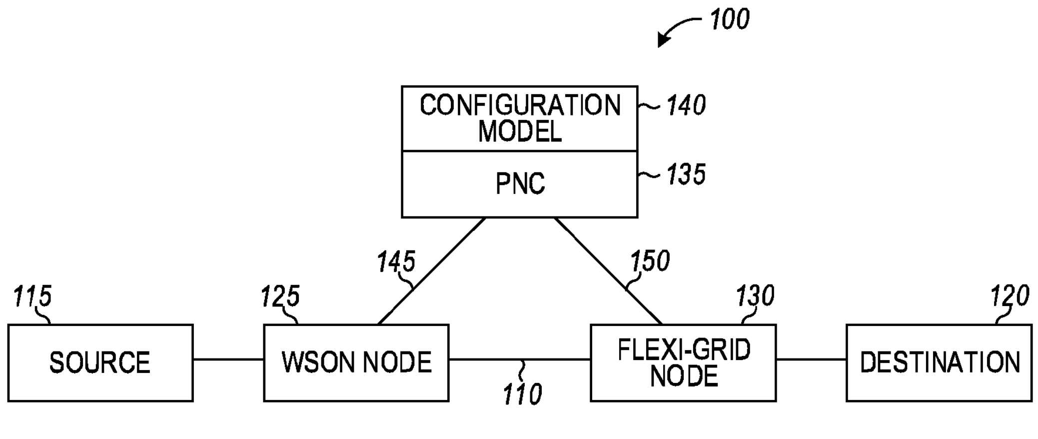
100
CONFIGURATION MODEL
140
PNC
135
145
150
115
125
130
120
SOURCE
WSON NODE
FLEXI-GRID NODE
DESTINATION
110

FIG. 1

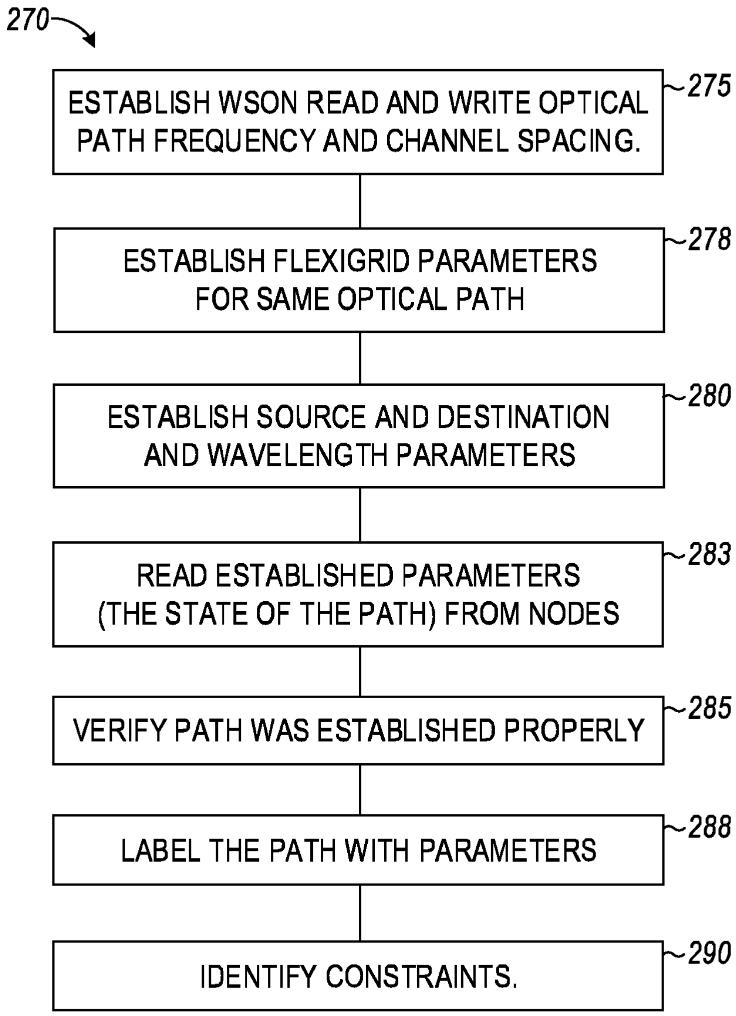
270
ESTABLISH WSON READ AND WRITE OPTICAL PATH FREQUENCY AND CHANNEL SPACING.
275
ESTABLISH FLEXIGRID PARAMETERS FOR SAME OPTICAL PATH
278
ESTABLISH SOURCE AND DESTINATION AND WAVELENGTH PARAMETERS
280
READ ESTABLISHED PARAMETERS (THE STATE OF THE PATH) FROM NODES
283
VERIFY PATH WAS ESTABLISHED PROPERLY
285
LABEL THE PATH WITH PARAMETERS
288
IDENTIFY CONSTRAINTS.
290

FIG. 2A

```
module: ietf-te-10 ~202
  augment /te:te/te:tunnels/te:tunnel/te:config: ~204
    +--rw (10-slot)? ~206
    |  +--:(wson) ~208
    |  |  +--rw selected frequency?      decimal64 ~210
    |  |  +--rw channel-spacing?         decimal64 ~212
    |  +--:(flexi-grid) ~214
    |     +--rw N?                       int32 ~216
    |     +--rw M?                       int32 ~218
    +--rw src-client-signal?       identityref ~220
    +--rw dst-client-signal?       identityref ~222
    +--rw wavelenght-assignment?   identityref ~224
  augment /te:te/te:tunnels/te:tunnel/te:state: ~226
    +--ro (10-slot)? ~228
    |  +--:(wson) ~230
    |  |  +--:ro selected-frequency?     decimal64 ~232
    |  |  +--:ro channel-spacing?        decimal64 ~234
    |  +--:(flexi-grid) ~236
    |     +--ro N?                       int32 ~238
    |     +--ro M?                       int32 ~240
    +--ro src-client-signal?       identityref ~242
    +--ro dst-client-signal?       identityref ~244
    +--ro wavelenght-assignment?   identityref ~246
  augment /te:te/te:lsps-state/te:lsp: ~248
    +--ro bidirectional?       boolean ~250
    +--ro (10-slot)? ~252
       +--:(wson) ~254
       |  +--ro selected frequency?      decimal64 ~256
       |  +--ro channel-spacing?         decimal64 ~258
       +--:(flexi-grid) ~260
          +--ro N?                       int32 ~262
          +--ro M?                       int32 ~264
  augment /te:te/te:globals/te:named-path-constraints/te:named-path-
constraint/te:config: ~266
    +--rw wavelenght-assignment?   identityref ~268
```

FIG. 2B

300

```
grouping tunnel-properties-10 {   310
    description
      "Configuration parameters relating to TE L0 TUNNEL
      attributes";

    choice 10-slot {   320
      description "This choice allows the selection of technology
        specifics.";
325   case wson {
        description "Configuration parameters relating to TE WSON TUNNEL
          attribute flags";

      leaf selected-frequency {
        type decimal64 {
          fraction-digits 5;
        }
        units THz;
        default 193.1;
        description "Selected Central Frequency";
      }

      leaf channel-spacing {
        type decimal64 {
          fraction-digits 5;
        }
        units GHz;
        description "This is fixed channel spacing for
             WSON, e.g, 12.5, 25, 50, 100, ..";
      }

    }
```

↓
3B

FIG. 3A

300

330

```
case flexi-grid {
        description "Configuration parameters relating to TE FLEXI-GRID
          TUNNEL attribute flags";
        reference "rfc7698";
        leaf N {
           type int32;
           description
              "Is used to determine the Nominal Central
              Frequency. The set of nominal central frequencies
              can be built using the following expression:
                 f = 193.1 THz + n x 0.00625 THz,
              where 193.1 THz is ITU-T ''anchor frequency'' for
              transmission over the c band, n is positive or
              negative integer including 0.";
           reference "rfc7698";
        }
        leaf M {
           type int32;
           description
              "Is used to determine the slot width. A slot width
              is constrained to be M x SWG (that is, M x 12.5 GHz).
              where M is an integer greater than or equal to 1.";
           reference "rfc7698";

      }

    }

  }

}
```

FIG. 3B

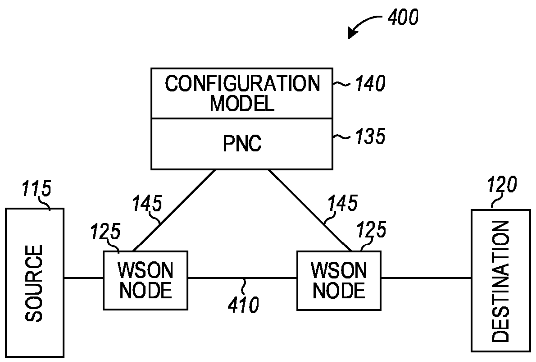
400
CONFIGURATION MODEL
140
PNC
135
115
SOURCE
145
145
125
125
WSON NODE
WSON NODE
410
120
DESTINATION

FIG. 4

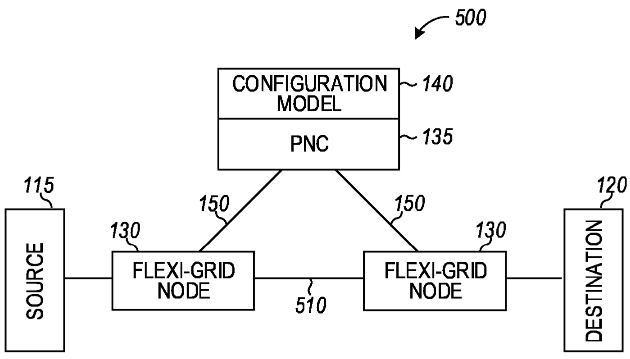
500
CONFIGURATION MODEL
140
PNC
135
115
SOURCE
150
150
130
130
FLEXI-GRID NODE
FLEXI-GRID NODE
510
120
DESTINATION

FIG. 5

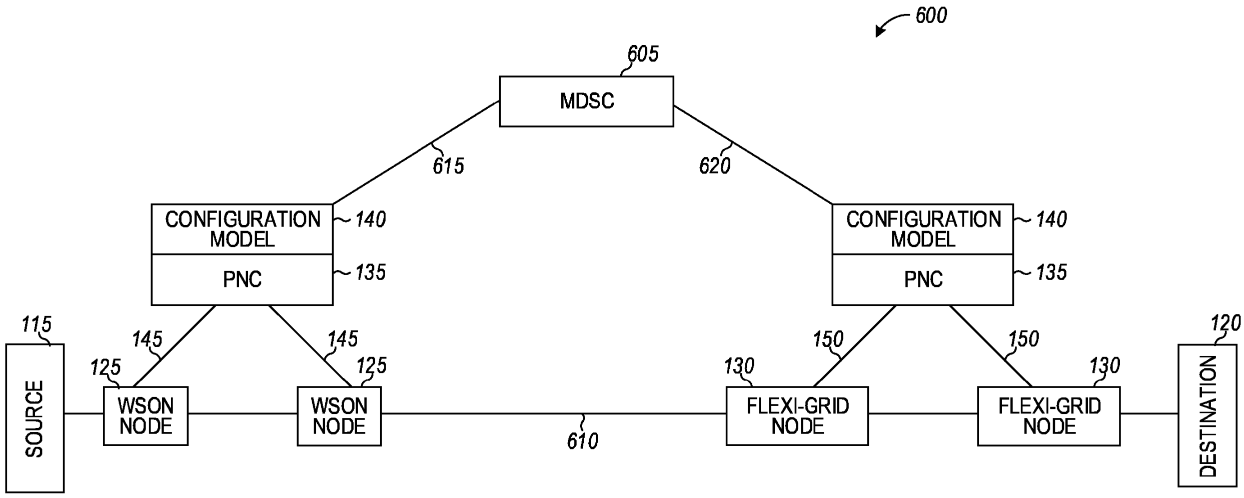
600
605
MDSC
615
620
CONFIGURATION MODEL
140
PNC
135
CONFIGURATION MODEL
140
PNC
135
115
SOURCE
145
145
125
125
WSON NODE
WSON NODE
610
150
150
130
130
FLEXI-GRID NODE
FLEXI-GRID NODE
120
DESTINATION

FIG. 6A

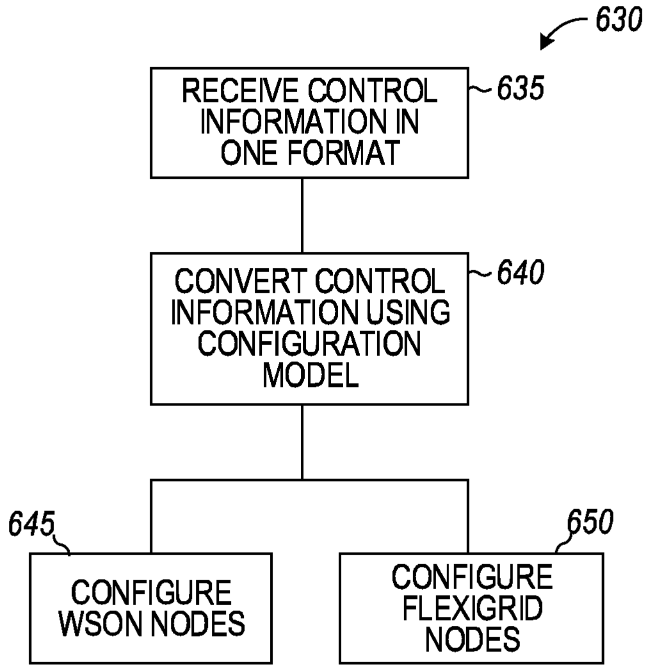
630
RECEIVE CONTROL INFORMATION IN ONE FORMAT
635
CONVERT CONTROL INFORMATION USING CONFIGURATION MODEL
640
645
CONFIGURE WSON NODES
650
CONFIGURE FLEXIGRID NODES

FIG. 6B

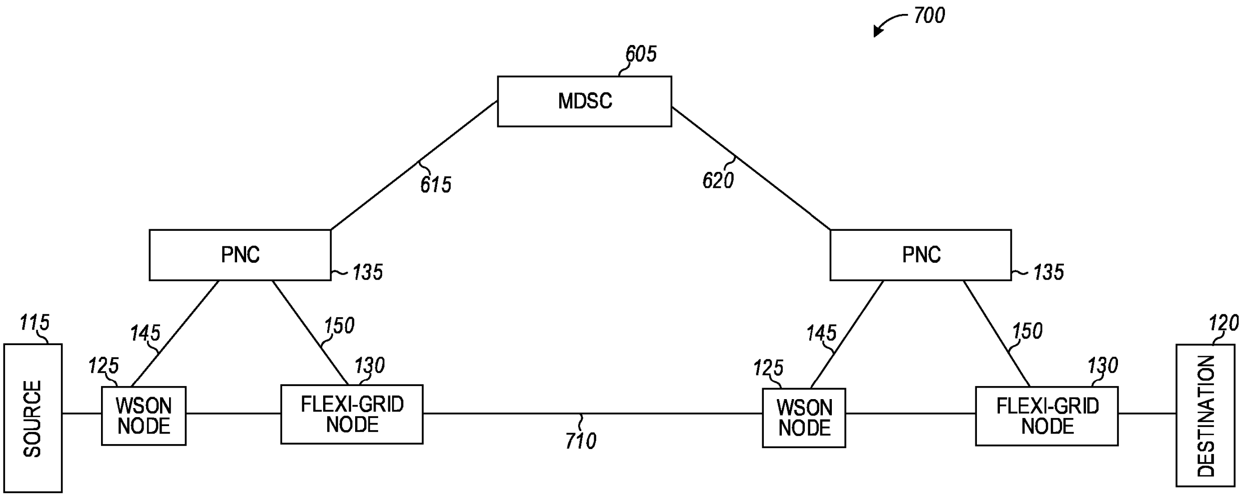
700
605
MDSC
615
620
PNC
135
PNC
135
115
145
150
145
150
120
125
130
125
130
SOURCE
WSON NODE
FLEXI-GRID NODE
710
WSON NODE
FLEXI-GRID NODE
DESTINATION

FIG. 7

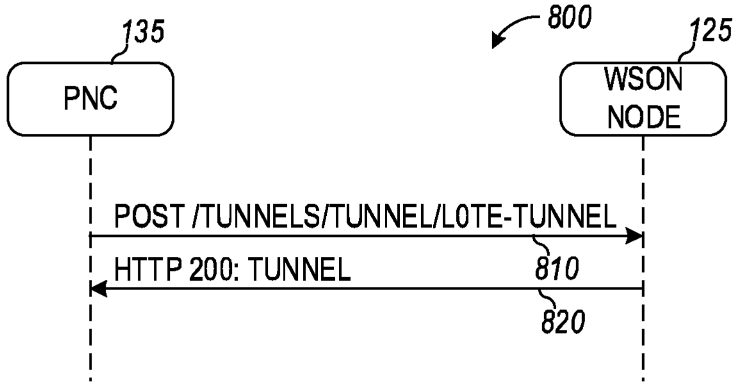
800
135
125
PNC
WSON NODE
POST /TUNNELS/TUNNEL/L0TE-TUNNEL
HTTP 200: TUNNEL
810
820

FIG. 8

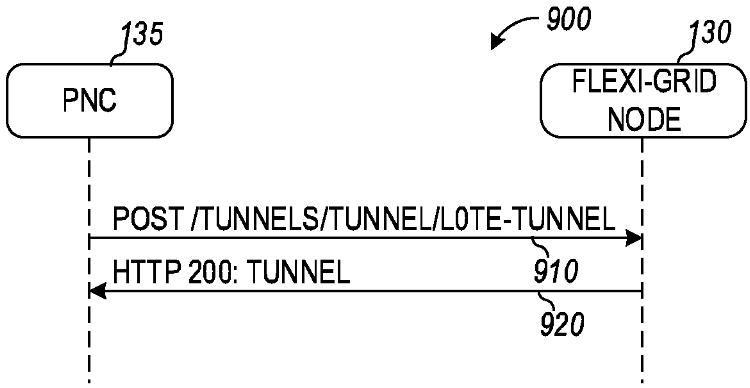
900
135
130
PNC
FLEXI-GRID NODE
POST /TUNNELS/TUNNEL/L0TE-TUNNEL
HTTP 200: TUNNEL
910
920

FIG. 9

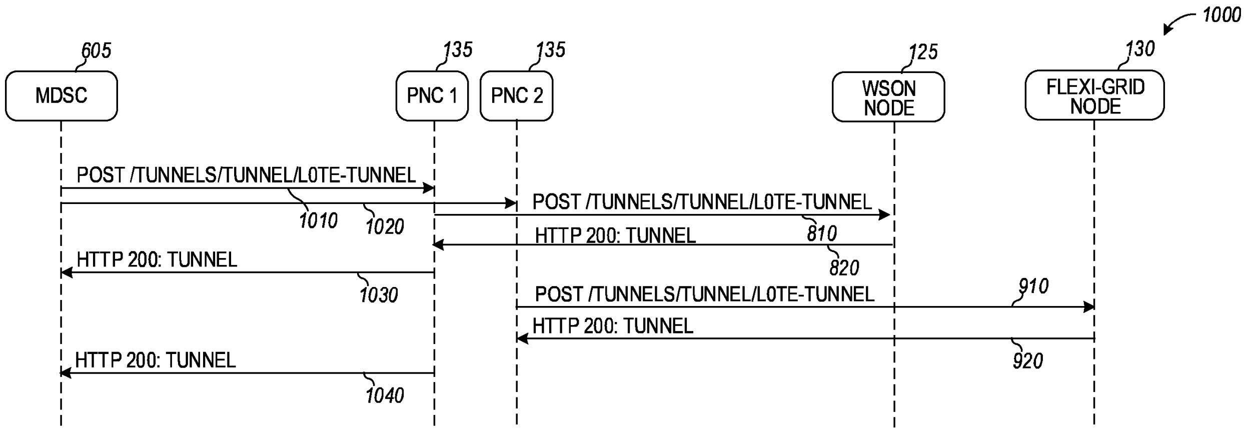
1000
605
MDSC
135
PNC 1
135
PNC 2
125
WSON NODE
130
FLEXI-GRID NODE
POST /TUNNELS/TUNNEL/L0TE-TUNNEL
1010
1020
POST /TUNNELS/TUNNEL/L0TE-TUNNEL
810
HTTP 200: TUNNEL
820
HTTP 200: TUNNEL
1030
POST /TUNNELS/TUNNEL/L0TE-TUNNEL
910
HTTP 200: TUNNEL
920
HTTP 200: TUNNEL
1040

FIG. 10

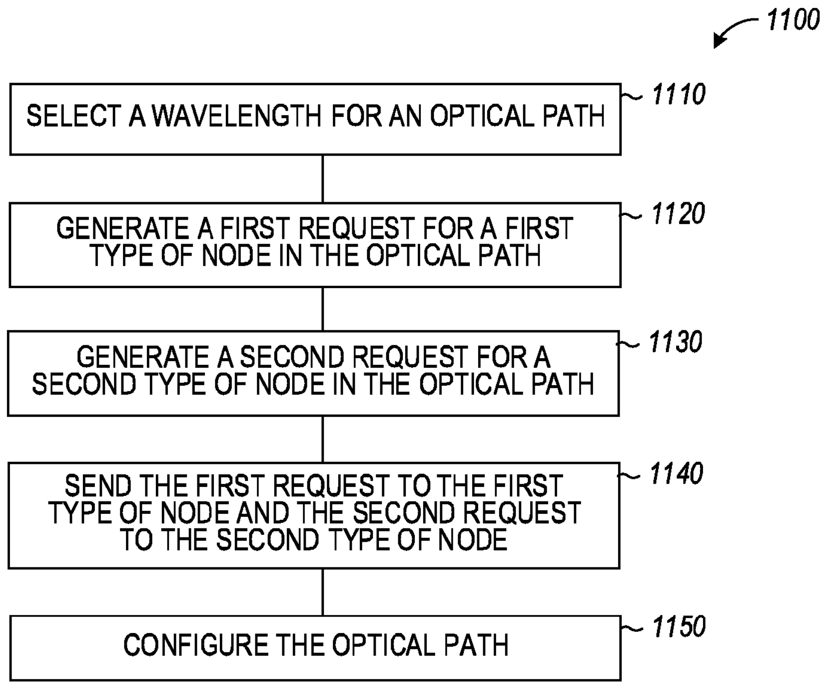
1100
SELECT A WAVELENGTH FOR AN OPTICAL PATH
1110
GENERATE A FIRST REQUEST FOR A FIRST TYPE OF NODE IN THE OPTICAL PATH
1120
GENERATE A SECOND REQUEST FOR A SECOND TYPE OF NODE IN THE OPTICAL PATH
1130
SEND THE FIRST REQUEST TO THE FIRST TYPE OF NODE AND THE SECOND REQUEST TO THE SECOND TYPE OF NODE
1140
CONFIGURE THE OPTICAL PATH
1150

FIG. 11

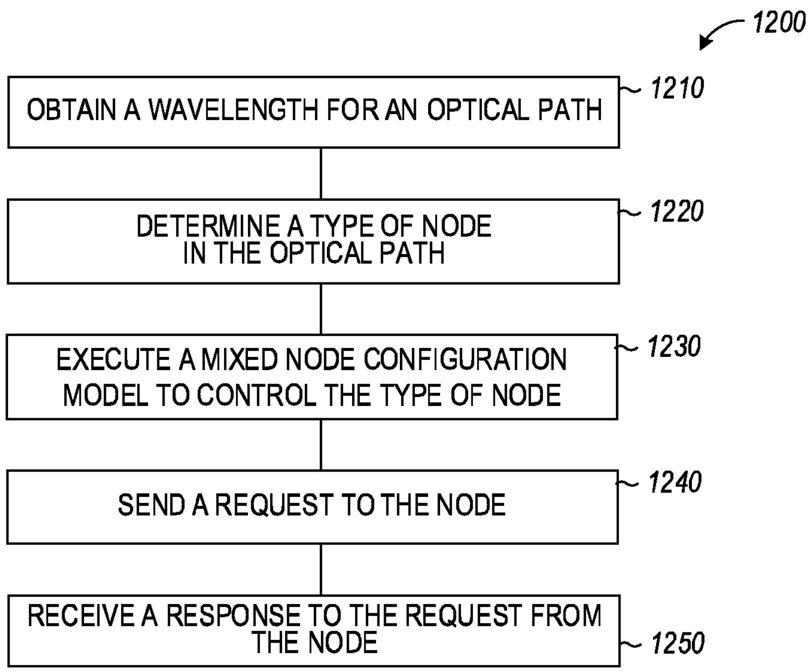
1200
OBTAIN A WAVELENGTH FOR AN OPTICAL PATH
1210
DETERMINE A TYPE OF NODE IN THE OPTICAL PATH
1220
EXECUTE A MIXED NODE CONFIGURATION MODEL TO CONTROL THE TYPE OF NODE
1230
SEND A REQUEST TO THE NODE
1240
RECEIVE A RESPONSE TO THE REQUEST FROM THE NODE
1250

FIG. 12

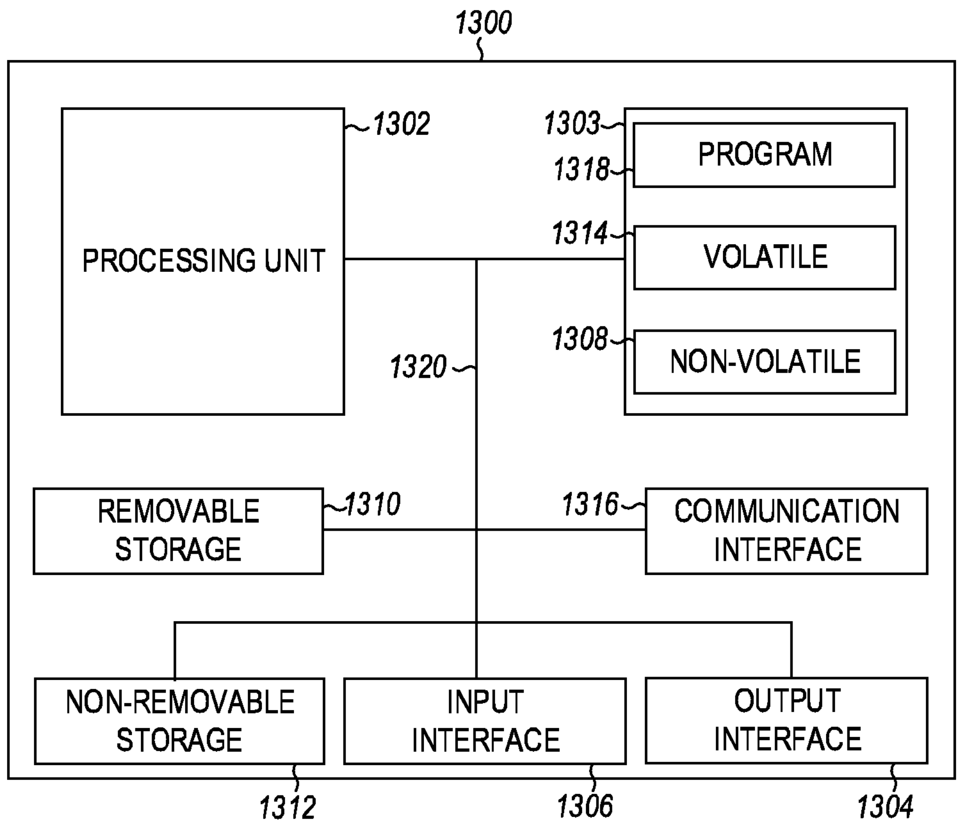
1300
PROCESSING UNIT
1302
1303
PROGRAM
1318
1314
VOLATILE
1308
NON-VOLATILE
1320
REMOVABLE STORAGE
1310
1316
COMMUNICATION INTERFACE
NON-REMOVABLE STORAGE
INPUT INTERFACE
OUTPUT INTERFACE
1312
1306
1304

FIG. 13

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **CHANNEGOWDA MAYUR et al.** *Software-defined optical networks technology and infrastructure: Enabling software-defined optical network operations [invited* **[0002]**