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(54) **CONTROLLER-TO-CONTROLLER INTERFACE FOR MULTI-LAYER NETWORK ABSTRACTION**

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H04L 41/12 (2022.01)
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CPC ***H04L 69/08*** (2013.01); ***H04L 41/12*** (2013.01); ***H04L 43/06*** (2013.01); ***H04L 69/18*** (2013.01); ***H04L 69/322*** (2013.01); *H04L 49/602* (2013.01)

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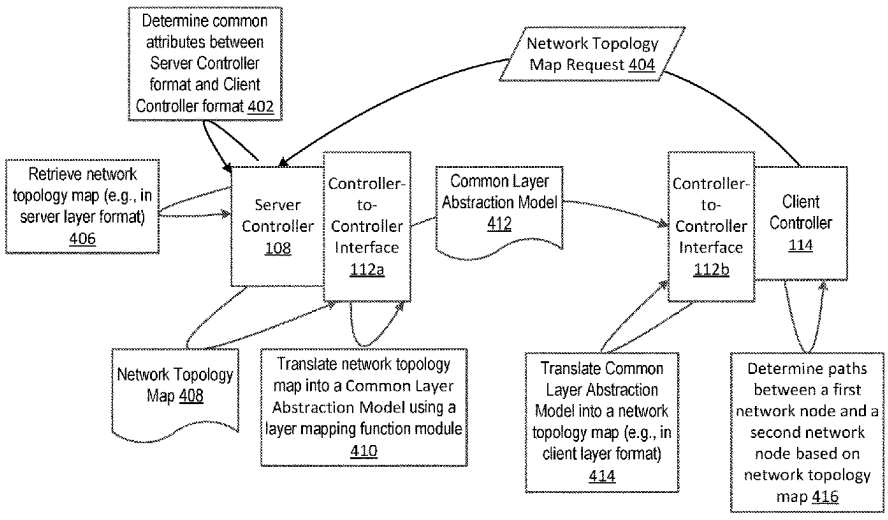
(57) **ABSTRACT**

A controller at an IP (e.g., client) layer in a multi-layer network can request a network topology map from another controller at an optical (e.g., server) layer in the multi-layer network. The controller at the optical layer of the network can use a layer mapping function and common attributes between the formats used to describe the network topology map at the two layers to generate a common layer abstraction model representing the network topology map stored at the controller at the optical layer of the network. A controller-to-controller interface can translate and/or send the common layer abstraction model to the controller at the IP layer for processing data on the network.

19 Claims, 6 Drawing Sheets



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See application file for complete search history.

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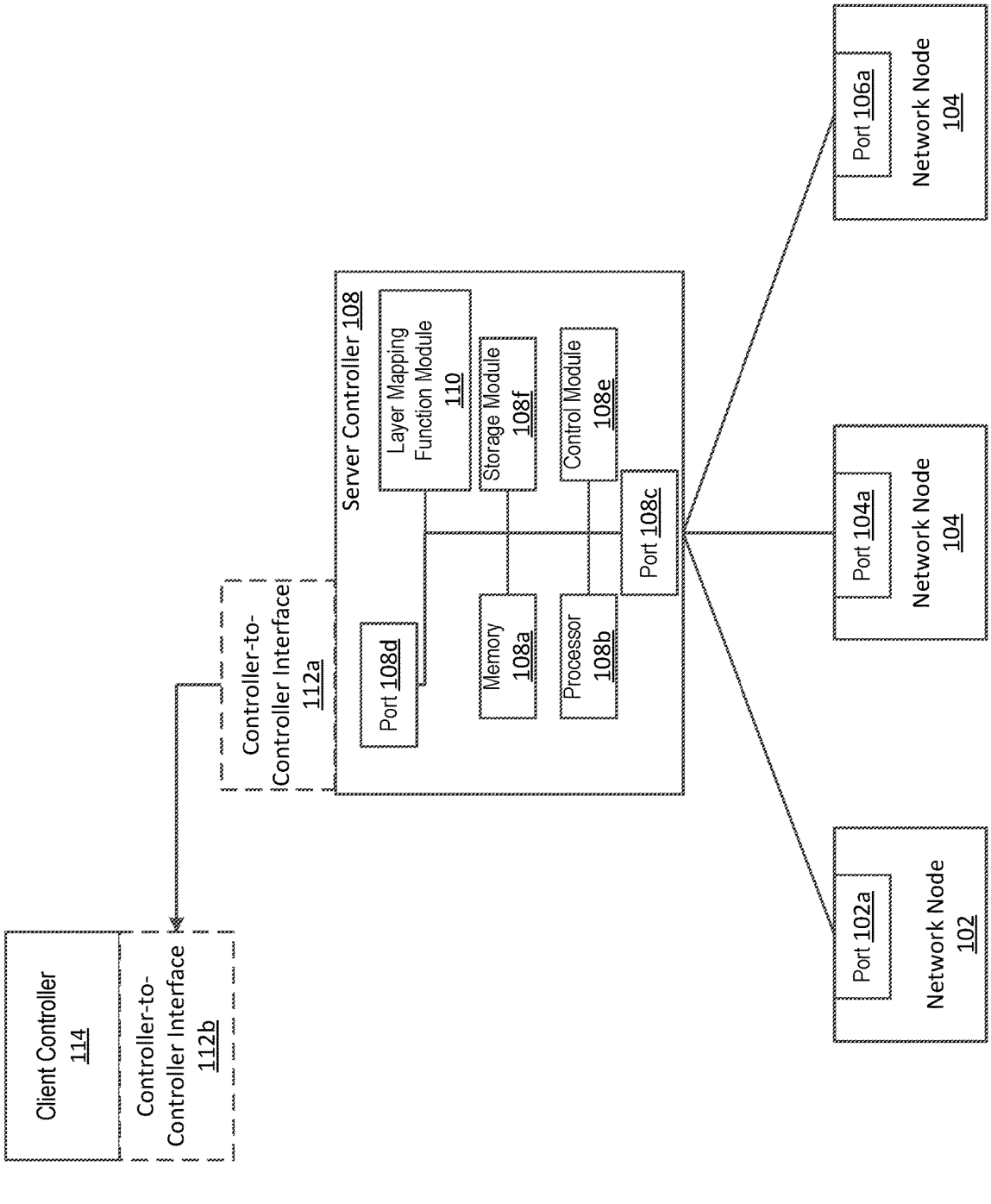
Client Controller 114
Controller-to-Controller Interface 112b
Controller-to-Controller Interface 112a
Server Controller 108
Port 108d
Layer Mapping Function Module 110
Memory 108a
Storage Module 108f
Processor 108b
Control Module 108e
Port 108c
Port 102a
Network Node 102
Port 104a
Network Node 104
Port 106a
Network Node 104

FIGURE 1

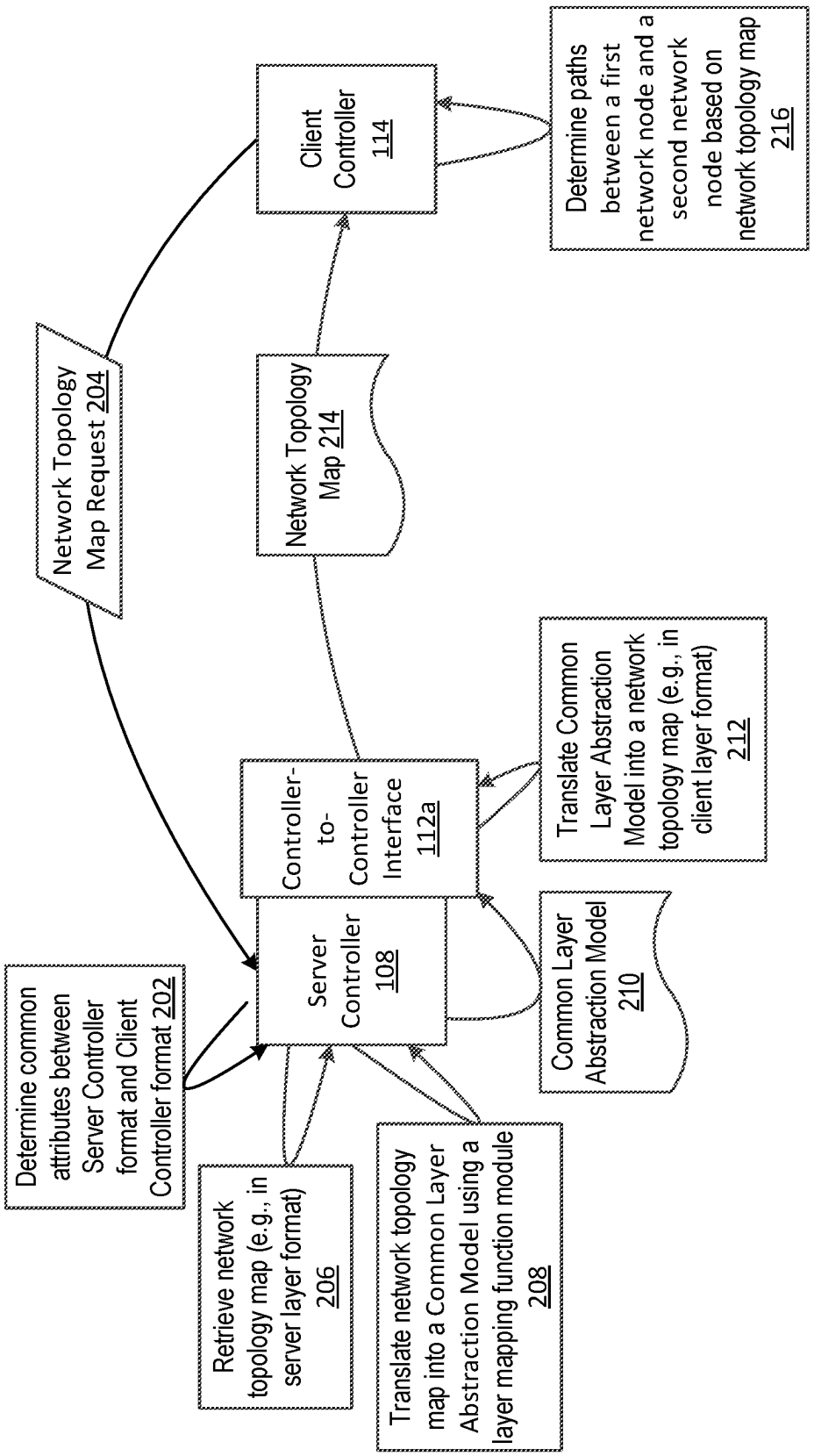
Client Controller 114
Determine paths between a first network node and a second network node based on network topology map 216
Network Topology Map Request 204
Network Topology Map 214
Controller-to-Controller Interface 112a
Translate Common Layer Abstraction Model into a network topology map (e.g., in client layer format) 212
Server Controller 108
Common Layer Abstraction Model 210
Determine common attributes between Server Controller format and Client Controller format 202
Retrieve network topology map (e.g., in server layer format) 206
Translate network topology map into a Common Layer Abstraction Model using a layer mapping function module 208

FIGURE 2

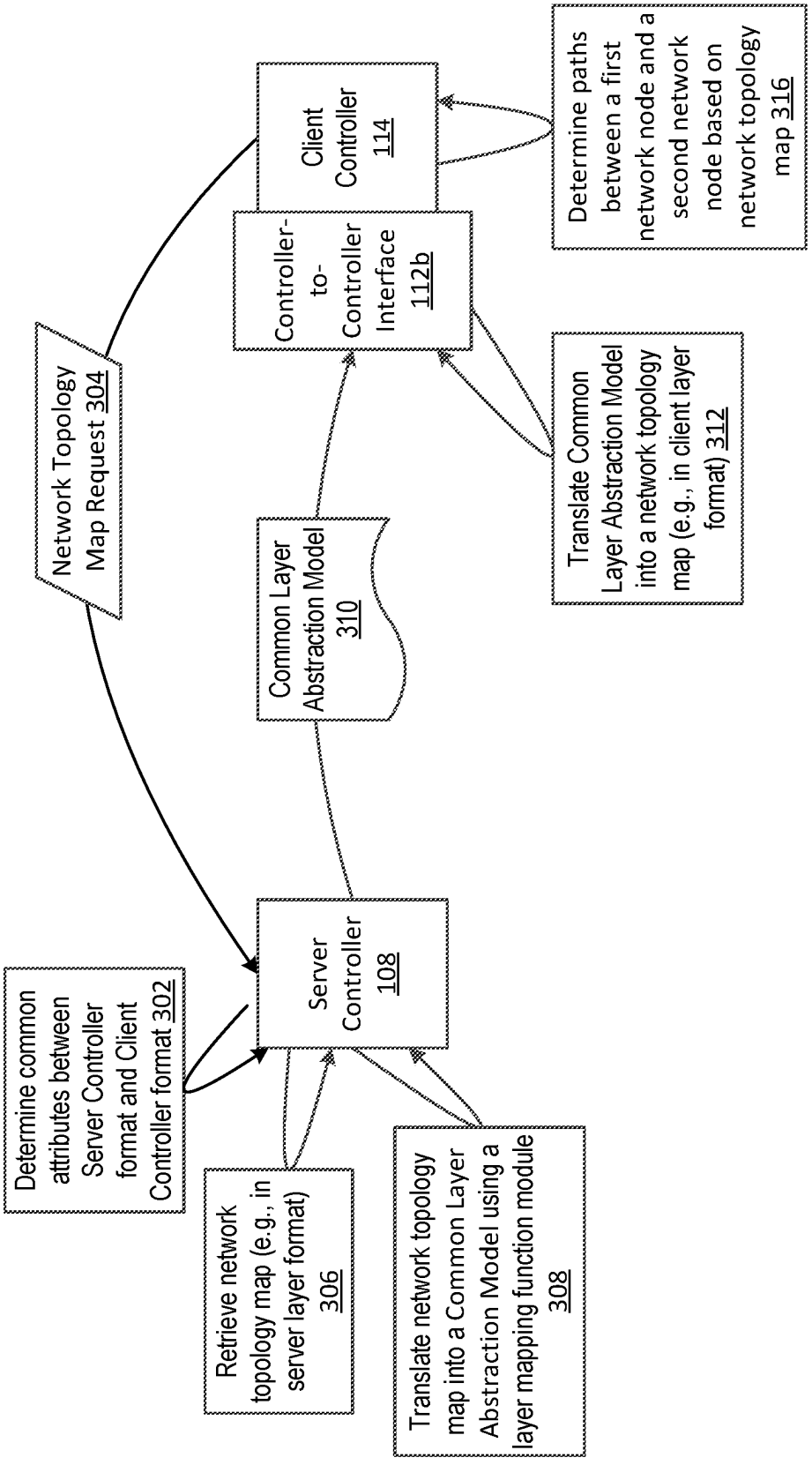
Client Controller 114
Controller-to-Controller Interface 112b
Server Controller 108
Network Topology Map Request 304
Common Layer Abstraction Model 310
Translate Common Layer Abstraction Model into a network topology map (e.g., in client layer format) 312
Determine paths between a first network node and a second network node based on network topology map 316
Determine common attributes between Server Controller format and Client Controller format 302
Retrieve network topology map (e.g., in server layer format) 306
Translate network topology map into a Common Layer Abstraction Model using a layer mapping function module 308

FIGURE 3

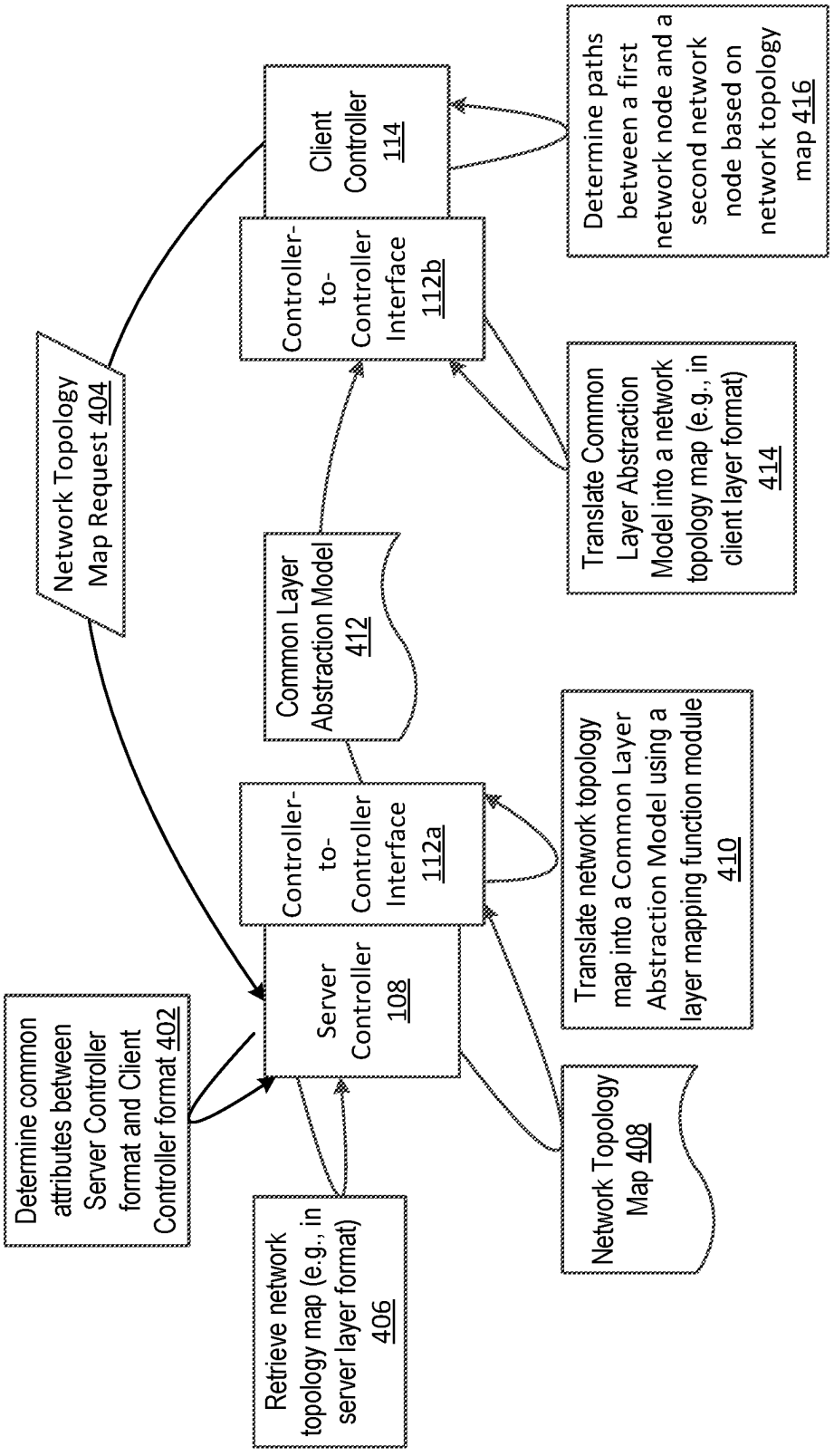
Determine common attributes between Server Controller format and Client Controller format 402
Server Controller 108
Controller-to-Controller Interface 112a
Client Controller 114
Controller-to-Controller Interface 112b
Network Topology Map Request 404
Common Layer Abstraction Model 412
Retrieve network topology map (e.g., in server layer format) 406
Network Topology Map 408
Translate network topology map into a Common Layer Abstraction Model using a layer mapping function module 410
Translate Common Layer Abstraction Model into a network topology map (e.g., in client layer format) 414
Determine paths between a first network node and a second network node based on network topology map 416

FIGURE 4

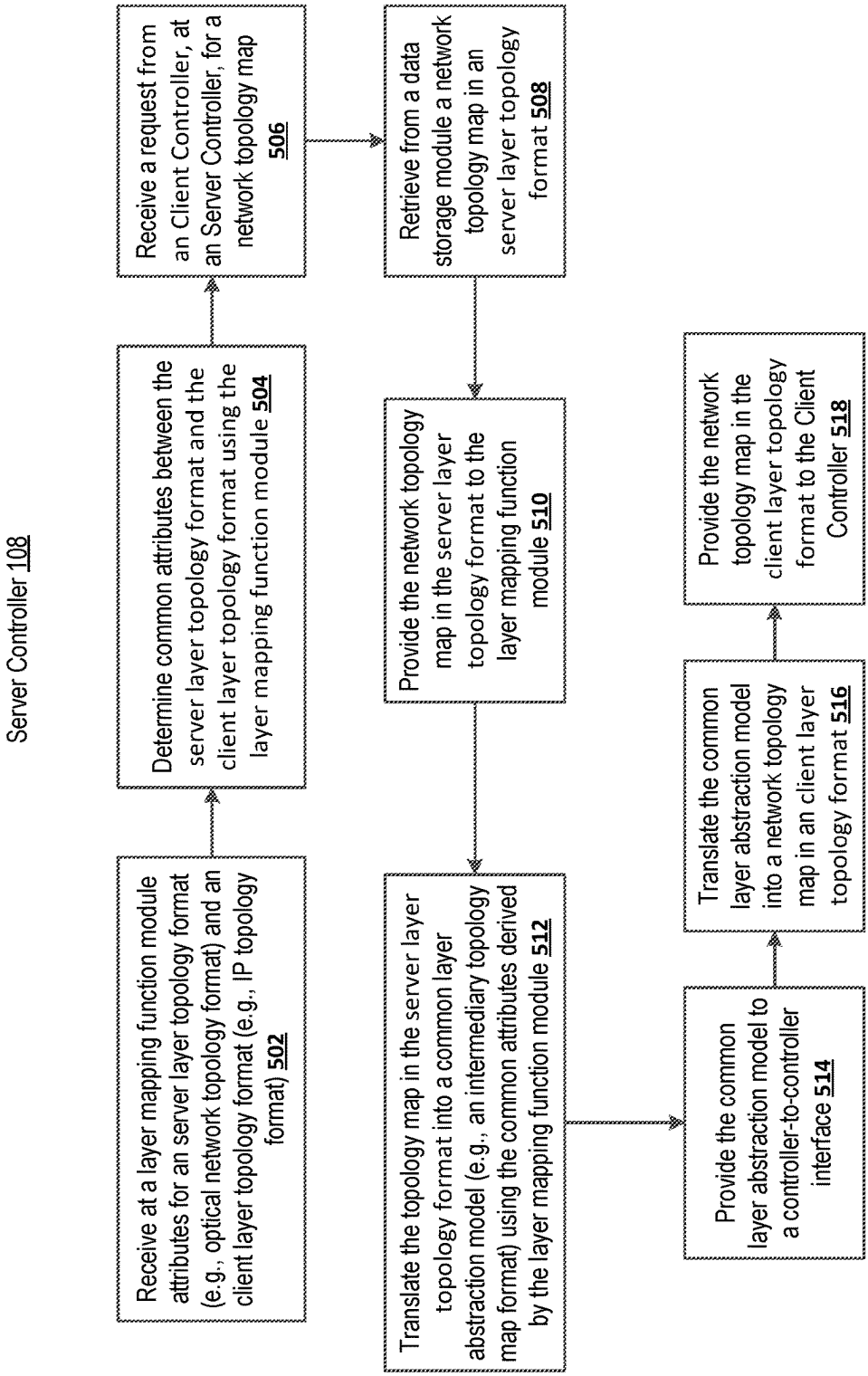
Server Controller 108
Receive at a layer mapping function module attributes for an server layer topology format (e.g., optical network topology format) and an client layer topology format (e.g., IP topology format) 502
Determine common attributes between the server layer topology format and the client layer topology format using the layer mapping function module 504
Receive a request from an Client Controller, at an Server Controller, for a network topology map 506
Retrieve from a data storage module a network topology map in an server layer topology format 508
Provide the network topology map in the server layer topology format to the layer mapping function module 510
Translate the topology map in the server layer topology format into a common layer abstraction model (e.g., an intermediary topology map format) using the common attributes derived by the layer mapping function module 512
Provide the common layer abstraction model to a controller-to-controller interface 514
Translate the common layer abstraction model into a network topology map in an client layer topology format 516
Provide the network topology map in the client layer topology format to the Client Controller 518

FIGURE 5

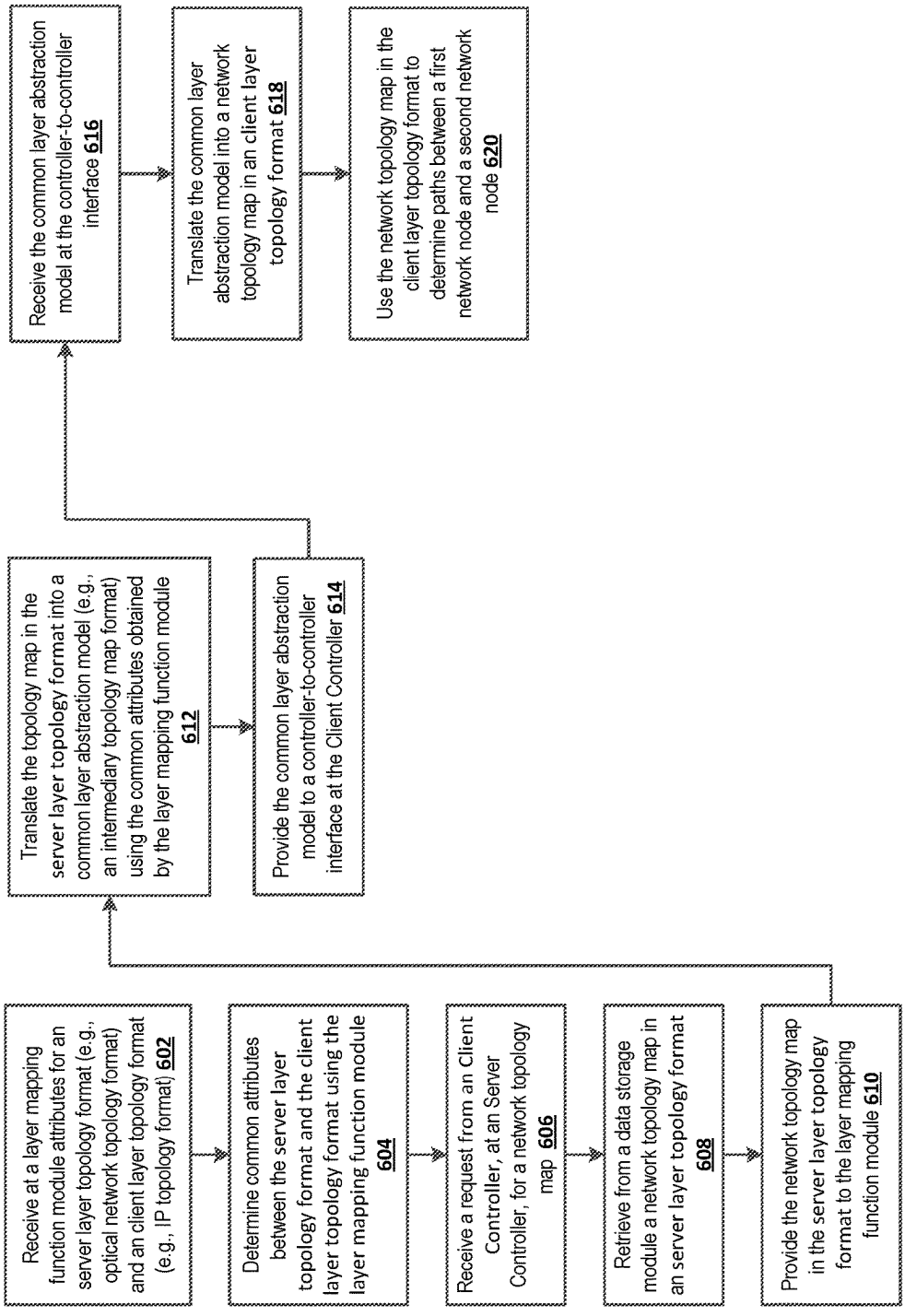
Server Controller 108
Client Controller 114
Receive at a layer mapping function module attributes for an server layer topology format (e.g., optical network topology format) and an client layer topology format (e.g., IP topology format) 602
Determine common attributes between the server layer topology format and the client layer topology format using the layer mapping function module 604
Receive a request from an Client Controller, at an Server Controller, for a network topology map 606
Retrieve from a data storage module a network topology map in an server layer topology format 608
Provide the network topology map in the server layer topology format to the layer mapping function module 610
Translate the topology map in the server layer topology format into a common layer abstraction model (e.g., an intermediary topology map format) using the common attributes obtained by the layer mapping function module 612
Provide the common layer abstraction model to a controller-to-controller interface at the Client Controller 614
Receive the common layer abstraction model at the controller-to-controller interface 616
Translate the common layer abstraction model into a network topology map in an client layer topology format 618
Use the network topology map in the client layer topology format to determine paths between a first network node and a second network node 620

FIGURE 6

CONTROLLER-TO-CONTROLLER INTERFACE FOR MULTI-LAYER NETWORK ABSTRACTION

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. patent application Ser. No. 14/515,074, filed Oct. 15, 2014, and entitled "Controller-To-Controller Interface for Multi-Layer Network Abstraction", the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

Some embodiments described herein relate generally to network systems, and more particularly, to systems and methods relating to abstracting layers of a multi-layer network.

Multi-layer networks have been widely used as a way of organizing network resources in a number of different ways to describe different network functionality and/or purposes. Each layer (also described herein as a domain) in a network can use different foundational technologies, which may not be inherently compatible with one another. For example optical network layers and IP network layers often use different communication protocols, represent links between network devices differently, are controlled differently, and/or the like.

Known networks have historically employed shared cross-layer formats for both optical network layers and IP network layers to represent links between network devices and/or like network attributes. For example, Generalized Multi-Protocol Label Switching (GMPLS) employs a single common control-plane representation for multiple layers of a multi-layer network. It also defines protocols such as Link Management Protocol (LMP), Resource Reservation Protocol (RSVP), and Open Shortest Path First (OSPF) to handle communications within and between network layers. This common representation for blending characteristics between the network layers, however, is often lacking in layer-specific optimizations that allow for faster processing of network functions within a particular layer. Additionally, a single common representation may prevent each layer from being able to evolve independently from other layers in the network, e.g., by requiring that each layer develop according to common constraints defined by the common representation.

Accordingly, a need exists for systems and methods that can allow network layers to communicate and share information with each other, while allowing for the network layers to continue to use protocols, network representation formats, and/or the like that are more specifically suited for the particular network layer.

SUMMARY

In some implementations, network layers can use the combination of a controller-to-controller interface (CCI) and a layer mapping function (LMF) module in tandem with various network inputs, to send, receive, and translate various communications between network layers. For example, the CCI and LMF at a first network controller at a first network layer can be used to translate network topology maps and/or like domain link representations into a common link abstraction model (CAM). The CAM can be interpreted by any of the network layers via their own CCI, and/or can be used to translate ingoing and/or outgoing communications into a format that can be interpreted by the recipient of the data.

Some implementations are directed to a system comprising a network entity at a first layer of a multilayer network, the entity at the first layer configured to receive a request for a network topology from a network entity at a second layer of a multilayer network. The network entity can use a layer mapping function module operatively coupled to the network entity at the first layer and configured to generate a translation protocol. The translation protocol is configured to determine common attributes between a first topology format and a second topology format. The network entity at the first layer of the multilayer network is configured to use the translation protocol to convert a topology map in the first topology format into a topology map in a third topology format. A multilayer network translation interface module is configured to use the topology map in the third topology format to generate a topology map in the second topology format. The network entity at the first layer is configured to send the topology map in the second topology format to the network entity at the second layer such that the entity at the second layer determines a path between a first network node and a second network node based on the topology map in the second topology format.

In further implementations, a system comprises a controller at a first layer of a multilayer network including a layer mapping function module. The layer mapping function module is configured to translate a network topology map in a first format and at the first layer of the multilayer network into a second format in response to a request for a network topology from a controller at a second layer. The controller at the first layer can be further configured to provide the network topology map in the second format to a controller-to-controller interface module configured to convert the network topology map to a third format and provide the network topology map in the third format to the controller at the second layer.

In further implementations, a method comprises receiving a signal, at a first controller at a first layer of a multilayer network from a second controller at a second layer in the multilayer network, requesting a network topology map in a second layer topology format. The method includes, in response to the signal, retrieving a network topology map in a first layer topology format at the first controller. The method further comprises translating the network topology map in the first layer topology format into a network topology map in an intermediary topology format using a layer mapping function module at the first controller, and translating the topology map in the intermediary topology format into a topology map in the second layer topology format using a controller-to-controller interface module. Finally, the method further comprises sending the topology map in the second layer topology format to the second controller.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of a network employing a controller-to-controller interface, according to an embodiment.

FIG. **2** is a flow diagram of providing a network topology map to a Client controller from a Server controller with a controller-to-controller interface, according to a first embodiment.

FIG. **3** is a flow diagram of providing a network topology map to a Client controller with a controller-to-controller interface from a Server controller, according to a second embodiment.

FIG. **4** is a flow diagram of providing a network topology map to a Client controller with a controller-to-controller interface from a Server controller with a controller-to-controller interface, according to a third embodiment.

FIG. **5** is a flow diagram of providing a network topology map to a Client controller from a Server controller with a controller-to-controller interface, according to an embodiment.

FIG. **6** is a flow diagram of providing a network topology map to a Client controller with a controller-to-controller interface from a Server controller, according to an embodiment.

DETAILED DESCRIPTION

FIG. **1** is a schematic illustration of a multi-layer network employing a multilayer network translation interface module (e.g., controller-to-controller interface **112***a* or **112***b*), according to an embodiment. In some implementations a multi-layer network can include network nodes **102**, **104**, and **106**. Each network node **102**, **104**, and **106** can be a network device including but not limited to a network switch, a network router, a network storage device, a network access device, and/or a similar network computing device. Each network node can include at least a memory and a processor and/or a set of processors, and can be configured to store processor-executable instructions in the memory to carry out various functions in the network.

In some implementations, network nodes **102**, **104**, and **106** can be operatively coupled to a network entity, such as a server layer controller **108** (e.g., including but not limited to a data link layer and/or a Layer 2 (L2) controller) situated in the second layer of the multi-layer network. Each of the network nodes **102**, **104**, and **106** can be operatively coupled to the Server controller **108**, for example, via a wired connection between at least one port **108***c* on the Server controller **108**, and ports **102***a*, **104***a*, and **106***a* on the network nodes **102**, **104**, and **106**, respectively. The second layer of the multi-layer network can be, for example, an optical (e.g., server) layer and/or domain, and can use formats such as but not limited to Device Management Interface (DMI) formats to represent the network topology of the network nodes **102**, **104**, and **106**. The Server controller **108** can be a switch device and/or other core server layer device, which can manage incoming and outgoing data in the optical layer of the network, e.g., by managing routing, processing, authenticating, and/or other actions performed on the data in the network. The Server controller **108** can include at least a memory **108***a* and a processor **108***b* and/or a set of processors, and can be configured to store processor-executable instructions in the memory, the instructions informing the processor of how to manage the network nodes **102**, **104**, and **106** and/or how to manage data being passed to and/or from the network nodes **102**, **104**, and **106**. The Server controller can also include a control module **108***e* for managing control of network operations and/or data (e.g., such as managing processing and encapsulation of data packets sent between network nodes **102**, **104**, and **106**, and/or controlling network nodes **102**, **104**, and **106**'s access to data), and a storage module **108***f* for persistent data storage. While not shown, multiple Server controllers can exist on the optical layer of the network, and can each be operatively coupled to a number of network nodes.

A Layer Mapping Function (LMF) module **110** can be a module operative within the Server controller **108**, and can be embodied in hardware (e.g., a modular hardware chip including processing hardware and data storage hardware, the modular hardware chip being operatively coupled to a network controller such as Server controller **108**) and/or software (e.g., a computer code module and/or a software object) stored or implemented in hardware. The LMF module **110** can be configured to define the connectivity between network layers and can extract common attributes between various network layers to define a function, model, and/or method of abstracting data (e.g., topology data) from any of the network layers. The LMF module **110** can be configured to provide this function, model, and/or abstraction method to the Server controller **108** to enable the Server controller **108** to define abstractions of data in, for example, an optical layer format (e.g., abstracting network topology representations described in an optical layer format). These abstractions can be translated and/or interpreted by other controllers in other network layers. An example of a LMF module model that describes communication between a server layer node (e.g., a network node on the data link and/or L2 layer) and a client layer controller **114** (e.g., including but not limited to a network layer and/or a Layer 3 (L3) controller) can take a form similar to the following:

```
1.1.1.1 1.1.1.2
+- - - - - - - - - - - - -+ +- - - - - - - - - - - - - - - -+
|IP Node1|<- - - - -LMF- - - - - ->|Optical node|
+- - - - - - - - - - - - -+ +- - - - - - - - - - - - - - - -+
Add: 10.1.1.1 10.1.1.2
ID: 12345 54321
100G Ethernet ODU4
NodeID: 1.1.1.1
To: 1.1.1.2, LocalIPaddr: 10.1.1.1, RemoteIPaddr:
  10.1.1.2
LocalIfIndex: 12345, RemoteIfIndex: 54321
Metric: 23
Bandwidth: 100 Gbps
Interface Switching Capability:
Local: Ethernet
Remote: Lambda
```

In some implementations, an example of an abstraction may be a common link abstraction model (CAM). A CAM can be a network layer-dependent model and/or representation of network layer data. For example, a CAM derived from a network topology map maintained at an optical layer of the network can specify a manner of describing links between network devices, which can be independent of the structure of the optical network layer and/or other specific constraints and/or properties of the optical network layer. The CAM can then be sent to other controllers in other network layers, e.g., can be sent to a Client controller **114**, which can interpret the CAM and generate a network topology map in its own client layer format (e.g., an Internet Protocol (IP) layer format defining IP-specific links and network properties). An example of a CAM description can take a form similar to the following:

```
+- - - - - - - - - - - - - - - - - - - - - - -+
|Optical Controller|- - - -CAM- - ->
+- - - - - - - - - - - - - - - - - - - - - - -+
||
+- - - - - - - - -DMI- - - - - - - - - - - - - - - - - - - - -
  - - - - - - - - - - - - - - - - - - - - - -+
| | |
1.1.1.2 V 1.1.1.3 V V 1.1.1.4
+- - - - - - - - - - - - - - - -+ +- - - - - - - - - - - - - - -
  -+ +- - - - - - - - - - - - - - - -+
```

|Optical Node1|<- - - - - - - - - ->|Optical node2|<- - - - - - - - ->| Optical node3|
+- - - - - - - - - - - - - - - - -+ +- - - - - - - - - - - - - - - - -+ +- - - - - - - - - - - - - - - - -+
<- -link ABC- ->
Add: 10.1.2.1 10.1.2.2
ID: 78901 10987
100G Lambda Lambda NodeID: 1.1.1.2
To: 1.1.1.4, LocalIPaddr: 10.1.2.1, RemoteIPaddr: 10.1.2.2
LocalIfIndex: 78901, RemoteIfIndex: 10987
Metric: 47
Bandwidth: 100 Gbps
Interface Switching Capability:
Local: Lambda
Remote: Lambda
Encoding: ODU4
Attributes:
SRLG: 5
Admin-group: Blue
Protected: False

A controller-to-controller interface **112***a* and **112***b* can be operatively coupled to the Server controller **110** and the Client controller **114**, respectively. The controller-to-controller interfaces **112***a-b* can be embodied in hardware (e.g., a modular hardware chip including processing hardware and data storage hardware, the modular hardware chip being operatively coupled to a network controller) and/or software (e.g., a computer code module stored or implemented in hardware, firmware, processor-executable instructions stored in memory, and/or the like stored or implemented in hardware). The controller-to-controller interfaces **112***a-b* can be configured to transfer the defined CAM to another network controller on another network layer, and/or to receive CAMs from other network controllers. The controller-to-controller interfaces **112***a-b* can also be configured to translate CAMs into formats associated with the particular network layer at which they are received.

For example, the controller-to-controller interface **112***a* can be configured to send a CAM representing the network topology map (e.g., defined in an optical layer format and maintained by the Server controller **108**) to Client controller **114**. The controller-to-controller interface **112***b* can also be configured to receive CAMs, e.g., from the Server controller **108**, and translate them into a client layer format (e.g., an IP layer format) for quick processing of the network topology map. In some implementations, controller-to-controller interface **112***a* may automatically translate a CAM into an client layer format, and send the client-layer-formatted network topology map to Client controller **114**, such that Client controller may not need a controller-to-controller interface **112***b* and/or other techniques for interpreting the CAM. In some implementations, Client controller **114** may be able to interpret the CAM without the use of a controller-to-controller interface **112***b* to translate the CAM into a client layer format, and may directly receive the CAM for processing. In other words, the functionality of a controller-to-controller interface can be included within a controller, and the controller-to-controller interface **112***b* and Client controller **114** need not be separate devices.

In some implementations, the LMF module **110** can reside in the controller-to-controller interface **112***a* instead of the Server controller **108**. In such implementations, the LMF module **110** can use a modified communication protocol (e.g., a modified version of LMP) to provide the CAM to the Server controller **108**, and/or the like.

Client controller **114** can be a network controller (e.g., a switch device and/or other core client layer device) situated in the third layer of the multi-layer network. The third layer of the multi-layer network can be an IP (e.g., client) layer and/or domain, and can use formats such as but not limited to Link State Database (LSDB) and/or Traffic-Engineering Database (TED) formats in order to represent the network topology of the network nodes **102**, **104**, and **106**. The Client controller **114** can manage incoming and outgoing data in the IP layer of the network, e.g., by managing routing, processing, authenticating, and/or other actions performed on the data in the network. The Client controller **114** can also include at least a memory and a processor and/or a set of processors, and can be configured to store processor-executable instructions in the memory, the instructions informing the processor of how to manage network nodes and/or how to manage data being passed to and/or from the network nodes. Client controller **114** can be operatively connected to a controller-to-controller interface **112***b*, which can receive and/or translate CAMs received by the Client controller **114** into a client layer (e.g., IP layer) format, e.g., an IP layer network topology map format, and/or the like. In some implementations, Client controller **114** may not be directly coupled to a controller-to-controller interface **112***b*, and may instead directly receive CAMs and/or IP-layer-formatted network topology map data from the controller-to-controller interface **112***a* operatively coupled to the Server controller. Although not shown, multiple Client controllers can operate on the IP layer of the network, and can each be operatively coupled to at least one Server controller at the optical layer of the network. Client controller **114** and/or other Client controllers in the network can also be operatively coupled to network nodes **102**, **104**, and **106**, and/or other network nodes in the network.

FIGS. **2-6** provide example implementations of the system described in FIG. **1**, it should be understood that the processes and functionality described in FIGS. **2-6** can be implemented using a variety of other network configurations and/or system arrangements, and are not limited to the structure embodied in FIG. **1**.

FIG. **2** is a flow diagram of providing a network topology map to a Client controller from a Server controller with a controller-to-controller interface **112***a*, according to an embodiment. In some implementations, the Server controller **108** can, using the LMF module **110** (e.g., shown in FIG. **1**), determine common attributes, at **202**, between the network topology format used by the optical layer and the Server controller **108**, and the network topology format used by the IP layer and the Client controller **114**. Determining common attributes can include determining common indicia each layer's format uses to describe a network link in a network topology map, to describe a path between network nodes, and/or the like. In some implementations the LMF module **110** can derive the common attributes based on a comparison of network topology maps in the two layers' formats, based on receiving attributes and/or descriptions of the layers' formats being compared, and/or the like. The LMF module **110** can alternatively receive data indicating the common attributes (e.g., from a network administrator, from data embedded in the LMF module **110**, and/or the like) instead of determining the attributes on its own.

The Client controller **114** can also generate and send a network topology map request **204** to the Server controller **108**. The network topology map request **204** can request a copy of the network topology map maintained by the Server controller **108**. The Client controller **114** can use the network topology map to determine how to route and/or manage data

packets in the network, how to link and/or otherwise associate network nodes, how to generate virtual network nodes to fulfill various network functions, and/or the like. In some implementations, the network topology map stored at the Server controller **108** and retrieved, at **206**, as a result of the request may not be in a format readable by the Client controller **114** (e.g., the network topology map can be in an optical layer format rather than an IP layer format, and/or the like). Storing the network topology map in an optical layer format can allow for faster processing of network information, as it can allow the optical layer to process data using a network topology map in a format that the optical layer can easily interpret, and can allow the optical layer to use optimizations inherent in the optical layer format to process the data. Thus, to provide the Client controller **114** with a network topology map representation that it can process, the Server controller **108** can use the LMF module **110** to translate, at **208**, the network topology map into a CAM **210**. The LMF module can, for example, generate, as the CAM **210**, a representation of the network topology map that uses the attributes common to the two layers' formats to describe the network links and communications.

Translating the network topology map into a CAM when the network topology map is requested by a controller at another layer allows the optical layer controllers (e.g., the Server controller **108**) to maintain the network topology map in a format optimized and/or streamlined for the functionality of the optical layer. Maintaining the network topology map in the optical layer format also allows the optical layer to include attributes and/or information specific to the nature of the optical layer. Translating the CAM also allows the Server controller **108** to still communicate the current topology of the network to other layers. Storing the CAM itself and/or a representation in a single common format would not allow for the same efficiency and/or ability to fully describe the network topology at the optical layer.

In some implementations, the CAM **210** generated by the LMF module **110** can be sent to a controller-to-controller interface **112***a*, which can be operatively coupled to the Server controller **108**. The controller-to-controller interface **112***a* can be configured to translate, at **212**, the CAM into a network topology map **214** in the IP layer format. The controller-to-controller interface **112***a* can also provide the network topology map **214** to the Client controller **114** via a signal to the Client controller **114**, which includes a representation of the network topology map **214**. The Client controller **114** can then determine paths (e.g., optimized paths, shortest paths, fastest paths, and/or the like) between a first network node in the network and a second network node **216** in the network based on the network topology map.

In some implementations, the CAM **210** can also be sent directly to the Client controller **114**, which can be configured to interpret the CAM **210** directly, and/or may be operatively coupled to a second controller-to-controller interface **112***b* (e.g., see FIGS. **3-4**), which is configured to translate the CAM into an IP layer format.

FIG. **3** is a flow diagram of providing a network topology map to a Client controller **114** operatively coupled to a controller-to-controller interface **112***b*, from a Server controller **108**, according to a second embodiment. Similar to the process shown in FIG. **2**, the Server controller **108** can use a LMF module **110** (e.g., shown in FIG. **1**) to determine common attributes, at **302**, between the layer formats of the Server controller **108** and the Client controller **114**. The Server controller can also retrieve, at **306**, the network topology map in the optical layer format, and the LMF module **110** can use the retrieved network topology map to translate, at **308**, the network topology map into a CAM **310**. In some implementations, the Server controller **108** can send the CAM **310** to the controller-to-controller interface **112***b*, e.g., via a signal to the controller-to-controller interface **112***b* including a representation of the CAM **310**. The controller-to-controller interface **112***b* can then translate, at **312**, the CAM **310** into a network topology map, e.g., in an IP layer format. The Client controller **114** can then use the network topology map in the IP layer format to determine, at **316**, paths between a first network node in the network and a second network node in the network.

In some implementations, the Client controller **114** can directly receive the CAM **310**, instead of receiving the translated network topology map from the controller-to-controller interface **112***b*. The Client controller **114** can be configured to interpret the CAM **310** directly, e.g., to update a network topology map stored at the Client controller **114**, in place of a network topology map in an IP layer format, and/or the like. In some implementations the Client controller **114** can also translate the CAM **310** into a network topology map, e.g., to store and/or process at the Client controller **114**.

FIG. **4** is a flow diagram of providing a network topology map to an Client controller **114** with a controller-to-controller interface **112***b* from an Server controller **108** with a controller-to-controller interface **112***a*, according to a third embodiment. In some implementations, multiple controllers in the multi-layer network can be operatively coupled to a given controller-to-controller interface configured to translate and/or process network topology maps for the particular controller(s) to which it is attached. The controller-to-controller interfaces can also be operatively coupled to a LMF module (not shown in FIG. **4**), e.g., instead of a controller being operatively coupled to a LMF controller. For example, similar to the process in FIG. **2**, the Server controller **108** can determine, at **402**, common attributes between the optical layer format and the IP layer format. The Server controller **108** can retrieve, at **406**, its representation of the network topology map **408** (e.g., in the optical layer format), and can provide the network topology map **408** to the controller-to-controller interface **112***a*.

The controller-to-controller interface **112***a* can translate, at **410**, the network topology map **408** into a CAM **412** of the network topology map, e.g., via the LMF module operatively coupled to the controller-to-controller interface **112***a*. The controller-to-controller interface **112***a* can send the CAM **412** to the controller-to-controller interface **112***b* operatively coupled to the Client controller **114**. The controller-to-controller interface **112***b* can translate, at **414**, the CAM **412** into a network topology map, e.g., in an IP layer format, and can provide the translated network topology map to the Client controller **114**. Alternatively, the controller-to-controller interface **112***b* can provide the Client controller **114** with the CAM directly. The Client controller **114** can then determine, at **416**, paths between a first network node in the network and a second network node in the network.

FIG. **5** is a flow diagram of providing a network topology map to a Client controller from a Server controller with a controller-to-controller interface, according to an embodiment. In some implementations, a Server controller **108** can receive (e.g., at a LMF module **110**, and/or directly at the Server controller **108**) attributes and/or descriptions relating to an optical layer's network topology format, as well as attributes and/or descriptions relating to an IP layer's network topology format, at **502**. The LMF module **110** can

determine common attributes and/or indicia between the optical layer's and the IP layer's network topology formats, at **504**, which can be used later to generate a CAM of the network topology map.

The Server controller **108** can receive a request from a Client controller **114** for a network topology map, at **506**, and can retrieve, in response to the request, a network topology map in an optical layer format, at **508**. The Server controller **108** can provide, at **510**, the network topology map to the LMF module **110**. The LMF module **110** translates, at **512**, the network topology map in the optical layer format into a CAM representing the network topology map, e.g., based on the common attributes derived by the LMF module **110**. The CAM can be an intermediary network topology map format, which can abstract the layer-specific details of the network topology map stored at the Server controller **108**, and can be used to translate the network topology map into other layer formats, and/or to interpret the network topology map at other network layers.

The LMF **110** can provide, at **514**, the CAM to a controller-to-controller interface **112***a* operatively coupled to the Server controller **108**. The controller-to-controller interface **112***a* can be configured to translate the common layer abstraction model into a network topology map in an IP layer format, at **516**. The network topology map in an IP layer and/or other client layer topology format can then be provided, at **518**, to the Client controller **114** for processing (e.g., to determine how to route data packets, and/or the like). Alternatively, the controller-to-controller interface **112***a* can send the CAM directly to the Client controller **114**, without translating it into an IP layer format, and the Client controller **114** can directly interpret the CAM to determine paths between network nodes.

FIG. **6** is a flow diagram of providing a network topology map to a Client controller **114** operatively coupled to a controller-to-controller interface, from a Server controller **108**, according to an embodiment. In some implementations, a Server controller **108** can receive (e.g., at a LMF module **110**, and/or directly at the Server controller **108**) attributes and/or descriptions relating to an optical layer's network topology format, as well as attributes and/or descriptions relating to an IP layer's network topology format, at **602**. The LMF module **110** can determine common attributes and/or indicia between the optical layer's and the IP layer's network topology formats, at **604**, which can be used later to generate a CAM of the network topology map.

The Server controller **108** can receive a request from a Client controller **114** for a network topology map, at **606**, and can retrieve, in response to the request, a network topology map in an optical layer format at **608**. The Server controller **108** can provide, at **610**, the network topology map to the LMF module **110**, the LMF module **110** being configured to translate, at **612**, the network topology map in the optical layer format into a CAM representing the network topology map, e.g., based on the common attributes derived by the LMF module **110**. The LMF module **110** can be configured to provide, at **614**, the CAM to a controller-to-controller interface **112***b* at the Client controller **114**. The controller-to-controller interface **112***b* at the Client controller **114** receives the CAM, at **616**, and translates the CAM into a network topology map, at **618**, in an IP layer and/or other client layer topology format. The network topology map in the IP layer format can then be used by the Client controller to determine paths between a first network node in the network and a second network node in the network, at **620**. In some implementations, the controller-to-controller interface **112***b* can provide the CAM directly to the Client controller for processing.

While embodiments herein relate to communications between an optical layer of a multi-layer network and a client layer of a multi-layer network, it should be understood that the embodiments can also be used with controllers on other layers of the multi-layer network.

Some embodiments described herein relate to devices with a non-transitory computer-readable medium (also can be referred to as a non-transitory processor-readable medium or memory) having instructions or computer code thereon for performing various computer-implemented operations. The computer-readable medium (or processor-readable medium) is non-transitory in the sense that it does not include transitory propagating signals per se (e.g., a propagating electromagnetic wave carrying information on a transmission medium such as space or a cable). The media and computer code (also can be referred to as code) may be those designed and constructed for the specific purpose or purposes. Examples of non-transitory computer-readable media include, but are not limited to: magnetic storage media such as hard disks, floppy disks, and magnetic tape; optical storage media such as Compact Disc/Digital Video Discs (CD/DVDs), Compact Disc-Read Only Memories (CD-ROMs), and holographic devices; magneto-optical storage media such as optical disks; carrier wave signal processing modules; and hardware devices that are specially configured to store and execute program code, such as Application-Specific Integrated Circuits (ASICs), Programmable Logic Devices (PLDs), Read-Only Memory (ROM) and Random-Access Memory (RAM) devices. Other embodiments described herein relate to a computer program product, which can include, for example, the instructions and/or computer code discussed herein.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Where methods and steps described above indicate certain events occurring in certain order, the ordering of certain steps may be modified. Additionally, certain of the steps may be performed concurrently in a parallel process when possible, as well as performed sequentially as described above. Although various embodiments have been described as having particular features and/or combinations of components, other embodiments are possible having any combination or sub-combination of any features and/or components from any of the embodiments described herein. Furthermore, although various embodiments are described as having a particular entity associated with a particular compute device, in other embodiments different entities can be associated with other and/or different compute devices.

What is claimed is:

1. A system, comprising:

a first controller configured to be coupled at a first layer of a multilayer network including a processor configured to translate a first network topology map in a first format and at the first layer of the multilayer network into a common link abstraction model (CAM) in response to a network topology map request from a second controller configured to be coupled at a second layer of the multilayer network, the CAM describing connections between network nodes from a plurality of network nodes that are operatively connected to (1) the first controller and (2) the second controller through the first controller such that the first controller is connected between the plurality of network nodes and the second

controller, the connections being independent of a topology of the first layer of the multilayer network, the CAM configured to abstract data (1) associated with the first layer and (2) of the first network topology map and specify information generated from the first network topology map and relating to common attributes between an abstraction of the first format and an abstraction of a second format, the first network topology map being stored at the first controller in an optical layer format,

the first controller configured to provide the CAM to a controller-to-controller interface, the controller-to-controller interface coupled to the second controller at the second layer, the controller-to-controller interface configured to convert the CAM into a second network topology map in the second format and provide the second network topology map to the second controller configured to (1) determine a fastest path between a first network node included in the plurality of network nodes and a second network node included in the plurality of network nodes based on the second network topology map and (2) generate virtual network nodes to perform network functions, based on the second network topology map, the second controller configured to not interpret the CAM.

2. The system of claim **1**, wherein:

the first layer is a server layer of the multilayer network, and the server layer is configured to use an optical domain protocol.

3. The system of claim **1**, wherein:

the second layer is a client layer of the multilayer network, and

the client layer is configured to use an internet protocol (IP) domain protocol.

4. The system of claim **1**, wherein:

the first format is an optical network topology format; and

the second format is an internet protocol (IP) topology format.

5. The system of claim **1**, wherein:

the first format is an optical network topology format,

the second format is an internet protocol (IP) topology format, and

the processor is configured to determine common attributes between the optical network topology format and the IP topology format.

6. The system of claim **1**, wherein:

the first format is an optical network topology format,

the second format is an internet protocol (IP) topology format, and

the CAM is configured to describe the first network topology map using common attributes between an abstraction of the optical network topology format and an abstraction of the IP topology format.

7. A method, comprising:

receiving a signal at a first controller at a first layer of a multilayer network from a second controller at a second layer in the multilayer network, the signal requesting a second network topology map in a second layer topology format, a first network topology map in a first layer topology format and being stored at a network entity at the first layer in an optical layer format;

in response to the signal, retrieving the first network topology map at the first controller;

translating the first network topology map into a common link abstraction model (CAM) using a processor at the first controller, the CAM describing connections between network nodes from a plurality of network nodes that are operatively connected to (1) the first controller and (2) the second controller through the first controller such that the first controller is connected between the plurality of network nodes and the second controller, the connections being independent of a topology of the first layer of the multilayer network, the CAM configured to abstract data (1) associated with the first layer and (2) of the first network topology map and specify information generated from the first network topology map and relating to common attributes between an abstraction of the first layer topology format and an abstraction of the second layer topology format; and

sending, by the first controller, the CAM to a controller-to-controller interface, the controller-to-controller interface (1) coupled to the second controller and (2) configured to translate the CAM into the second network topology map and send the second network topology map to the second controller such that the second controller (1) determines at least one of a shortest path or a fastest path between a first network node included in the plurality of network nodes and a second network node included in the plurality of network nodes based on the second network topology map and (2) generates virtual network nodes to fulfill network functions, the second controller not configured to interpret the CAM.

8. The method of claim **7**, wherein:

the first layer is a client layer of the multilayer network, and

the client layer uses an internet protocol (IP) domain protocol.

9. The method of claim **7**, wherein:

the second layer is a server layer of the multilayer network, and

the server layer uses an optical domain protocol.

10. The method of claim **7**, wherein the network entity interprets the first network topology map using optimizations inherent to the optical layer format.

11. The method of claim **7**, wherein the first network topology map includes attributes specific to the first layer in the optical layer format.

12. The method of claim **7**, wherein the common attributes include common indicia within the first layer topology format and the second layer topology format, the common indicia indicative of: (1) a network link in at least one of the first network topology map or the second network topology map, (2) a path between network nodes represented within at least one of the first network topology map or the second network topology map, and (3) a network node represented within at least one of the first network topology map or the second network topology map.

13. A non-transitory, processor-readable medium storing instructions that when executed by a processor, cause the processor to:

receive a signal at a first controller at a first layer of a multilayer network from a second controller at a second layer in the multilayer network, the signal requesting a second network topology map in a second layer topology format, a first network topology map in a first layer topology format and being stored at a network entity at the first layer in an optical layer format;

in response to the signal, retrieve the first network topology map at the first controller;

translate the first network topology map into a common link abstraction model (CAM) using the processor at the first controller, the CAM describing connections

between network nodes from a plurality of network nodes that are operatively connected to (1) the first controller and (2) the second controller through the first controller such that the first controller is connected between the plurality of network nodes and the second controller, the connections being independent of a topology of the first layer of the multilayer network, the CAM configured to abstract data (1) associated with the first layer and (2) of the first network topology map and specify information generated from the first network topology map and relating to common attributes between an abstraction of the first layer topology format and an abstraction of the second layer topology format; and

send, by the first controller, the CAM to a controller-to-controller interface, the controller-to-controller interface (1) coupled to the second controller and (2) configured to translate the CAM into the second network topology map and send the second network topology map to the second controller such that the second controller (1) determines at least one of a shortest path or a fastest path between a first network node included in the plurality of network nodes and a second network node included in the plurality of network nodes based on the second network topology map and (2) generates virtual network nodes to fulfill network functions, the second controller not configured to interpret the CAM.

14. The non-transitory, processor-readable medium of claim **13**, wherein:

the first layer is a client layer of the multilayer network, and

the client layer uses an internet protocol (IP) domain protocol.

15. The non-transitory, processor-readable medium of claim **13**, wherein:

the second layer is a server layer of the multilayer network, and

the server layer uses an optical domain protocol.

16. The non-transitory, processor-readable medium of claim **13**, wherein the network entity interprets the first network topology map using optimizations inherent to the optical layer format.

17. The non-transitory, processor-readable medium of claim **13**, wherein the first network topology map includes attributes specific to the first layer in the optical layer format.

18. The non-transitory, processor-readable medium of claim **13**, wherein the common attributes include common indicia within the first layer topology format and the second layer topology format, the common indicia indicative of: (1) a network link in at least one of the first network topology map or the second network topology map, (2) a path between network nodes represented within at least one of the first network topology map or the second network topology map, and (3) a network node represented within at least one of the first network topology map or the second network topology map.

19. The non-transitory, processor-readable medium of claim **13**, wherein the second controller determines the shortest path and the fastest path between the first network node and the second network node.

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