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Harneja et al.

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(54) **VALIDATION OF LAYER 3 BRIDGE DOMAIN SUBNETS IN IN A NETWORK**

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H04L 12/24 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 41/0866*** (2013.01); ***H04L 41/0266*** (2013.01); ***H04L 41/0853*** (2013.01); ***H04L 41/0873*** (2013.01); ***H04L 41/0893*** (2013.01); ***H04L 41/12*** (2013.01)

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

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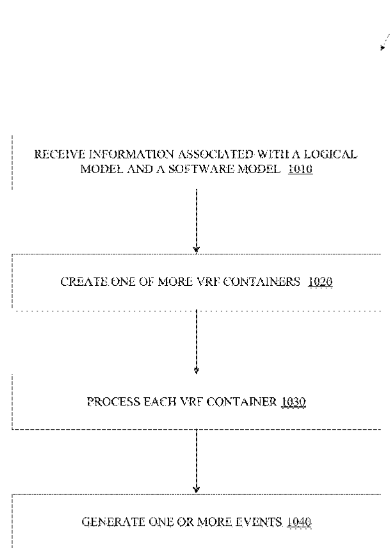
Primary Examiner — Brian Whipple
(74) *Attorney, Agent, or Firm* — Polsinelli PC

(57) **ABSTRACT**

Disclosed are systems, methods, and computer-readable media for assuring tenant forwarding in a network environment. Network assurance can be determined in layer 1, layer 2 and layer 3 of the networked environment including, internal-internal (e.g., inter-fabric) forwarding and internal-external (e.g., outside the fabric) forwarding in the networked environment. The network assurance can be performed using logical configurations, software configurations and/or hardware configurations

20 Claims, 29 Drawing Sheets



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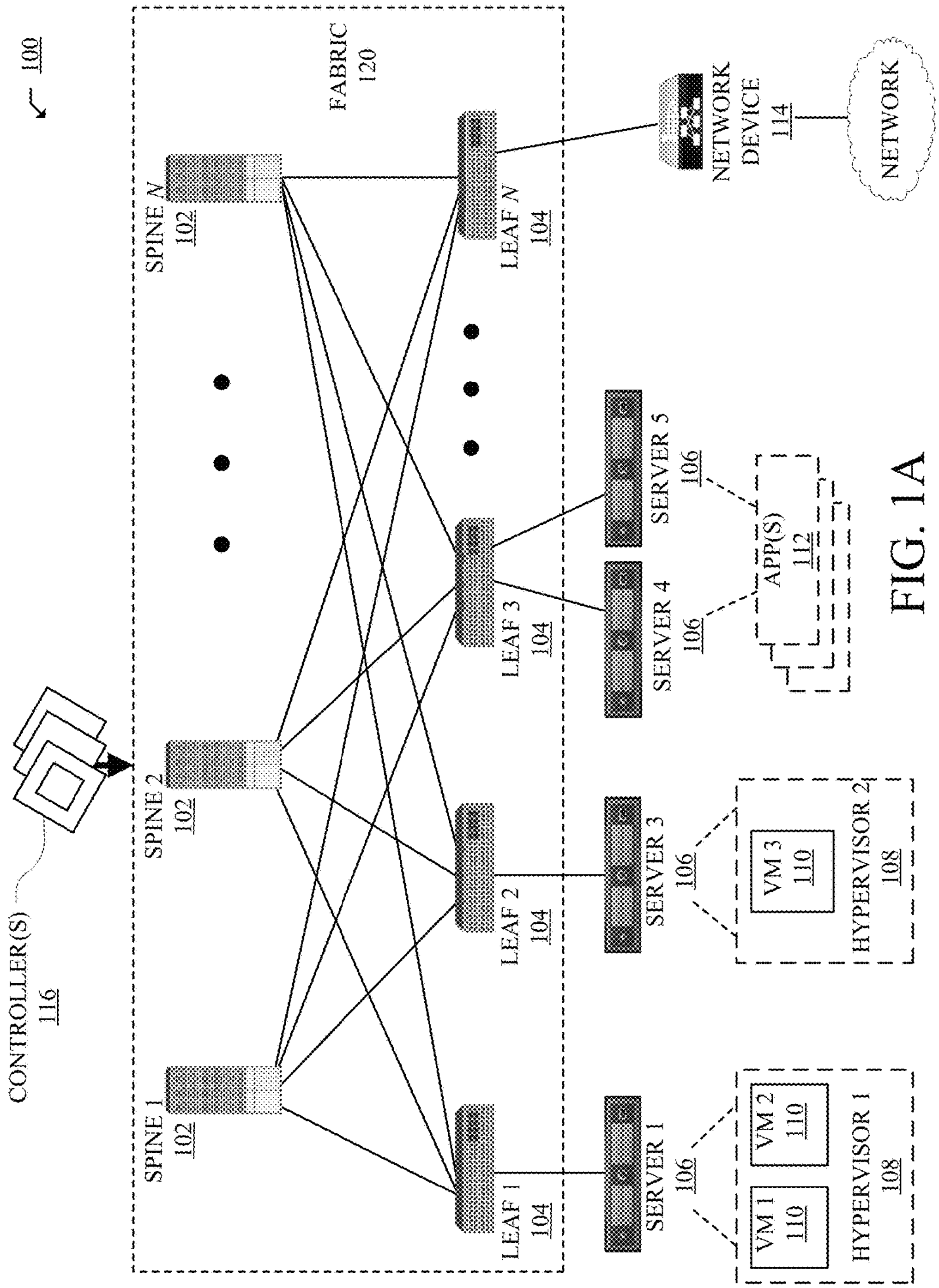
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106
SERVER 5
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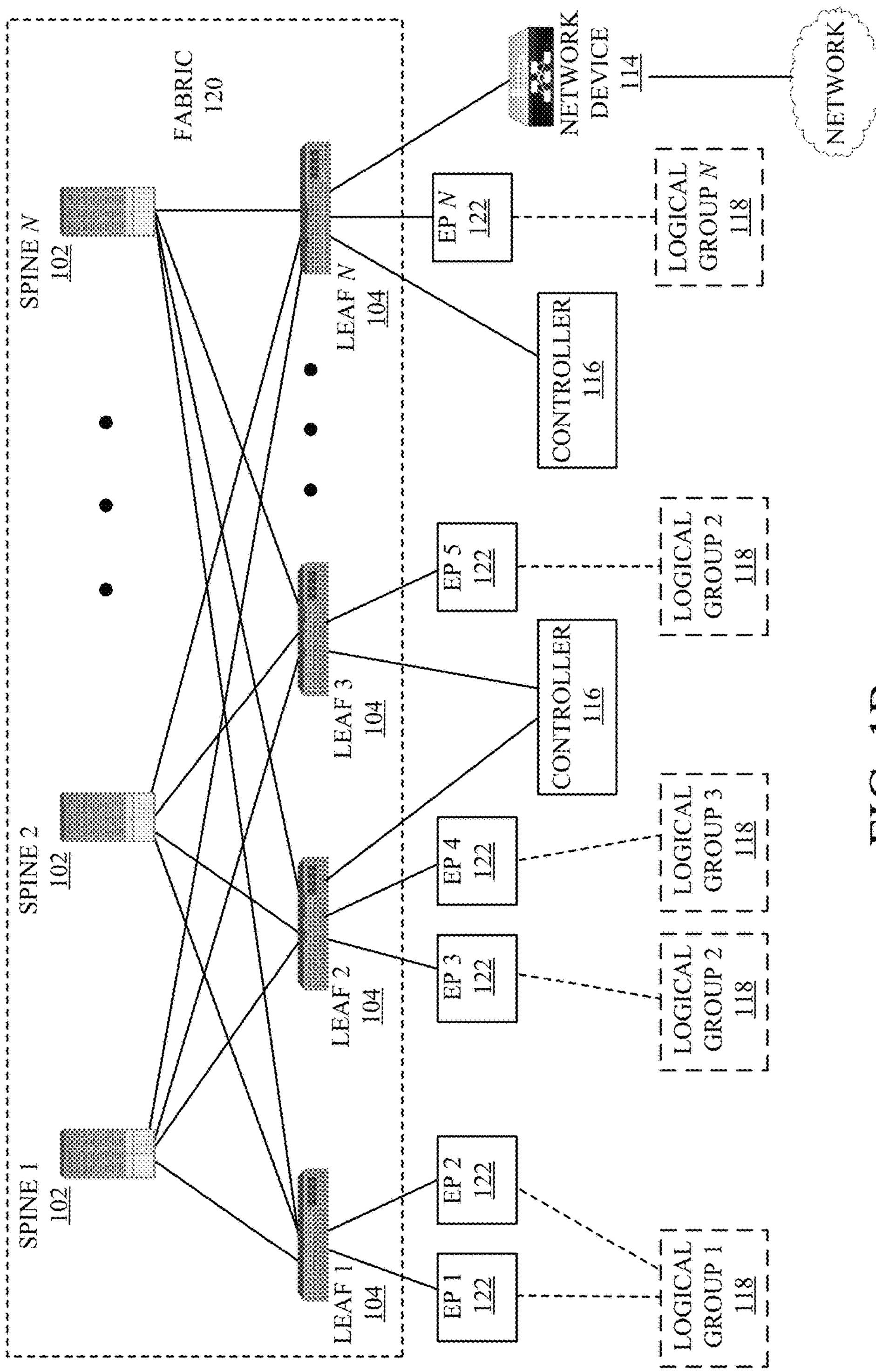
HYPERVISOR 2
108

FIG. 1A



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EP 1
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EP 2
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EP 3
122
EP 4
122
EP 5
122
EP N
122
CONTROLLER
116
CONTROLLER
116
LOGICAL
GROUP 1
118
LOGICAL
GROUP 2
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GROUP 3
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GROUP 2
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LOGICAL
GROUP N
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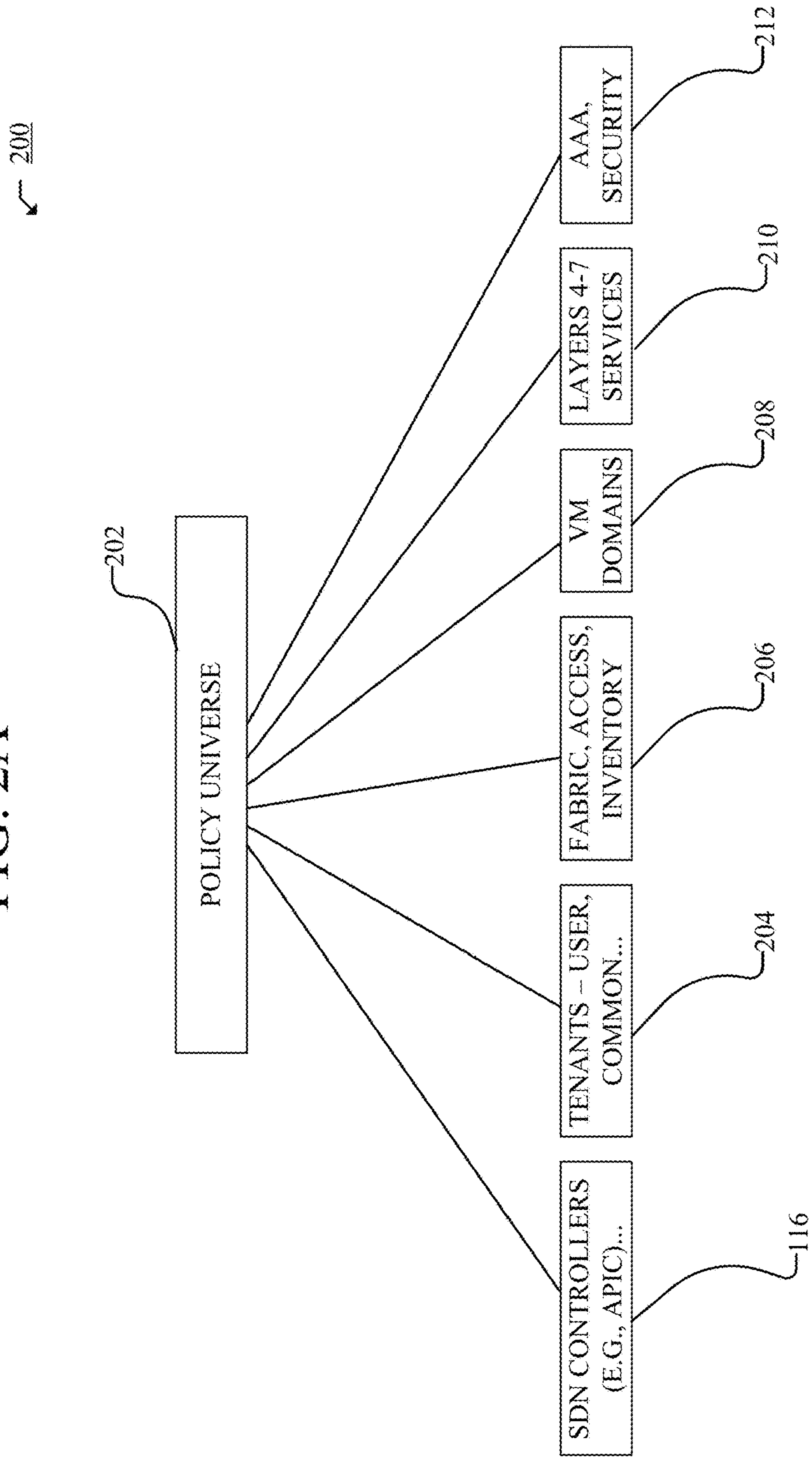
NETWORK
DEVICE
114
NETWORK

FIG. 1B

FIG. 2A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VM DOMAINS
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LAYERS 4-7 SERVICES
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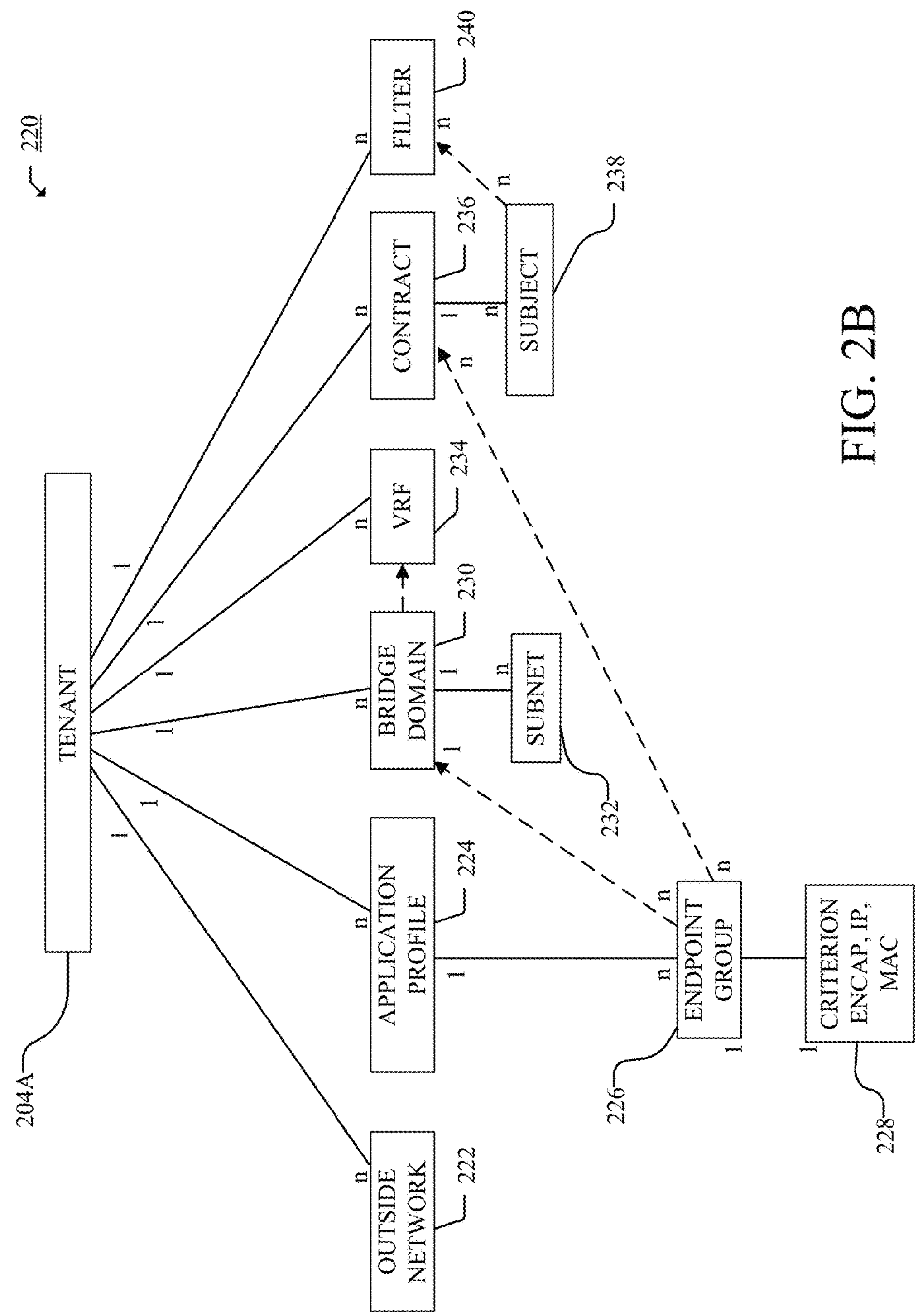
AAA, SECURITY
212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SUBNET
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SUBJECT
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FILTER
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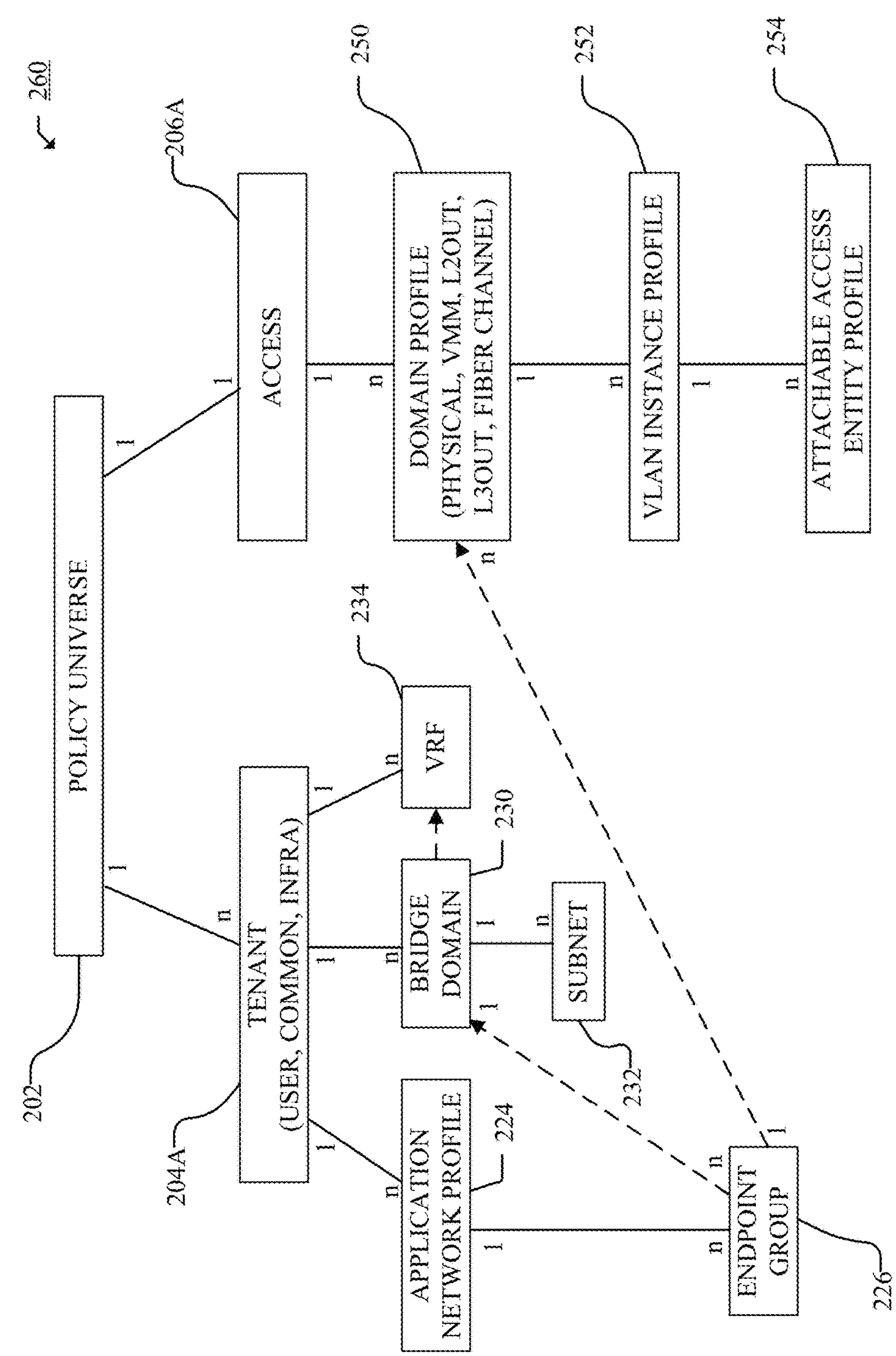
FIG. 2B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ACCESS
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VLAN INSTANCE PROFILE
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ATTACHABLE ACCESS ENTITY PROFILE
254
TENANT (USER, COMMON, INFRA)
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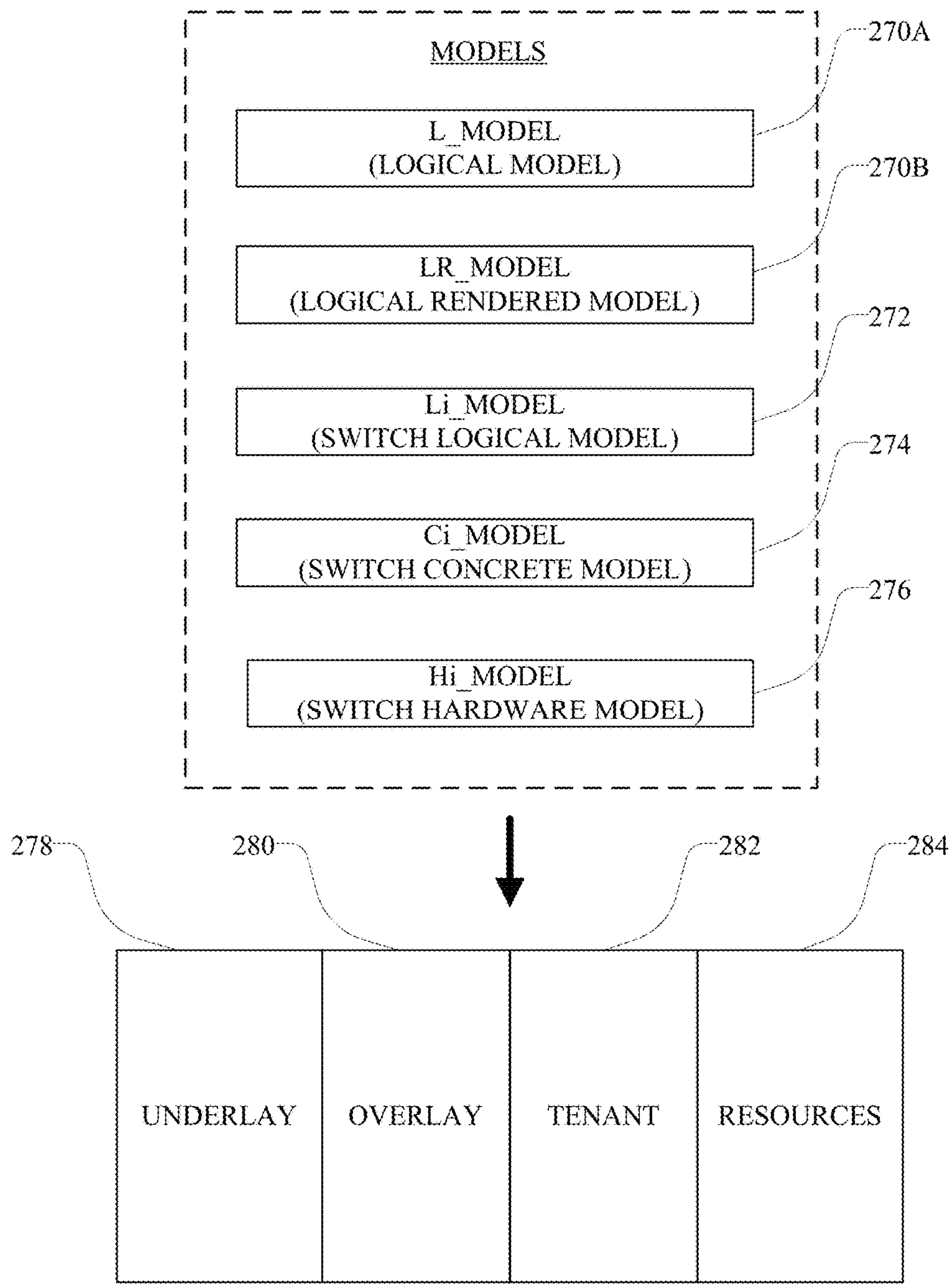
FIG. 2C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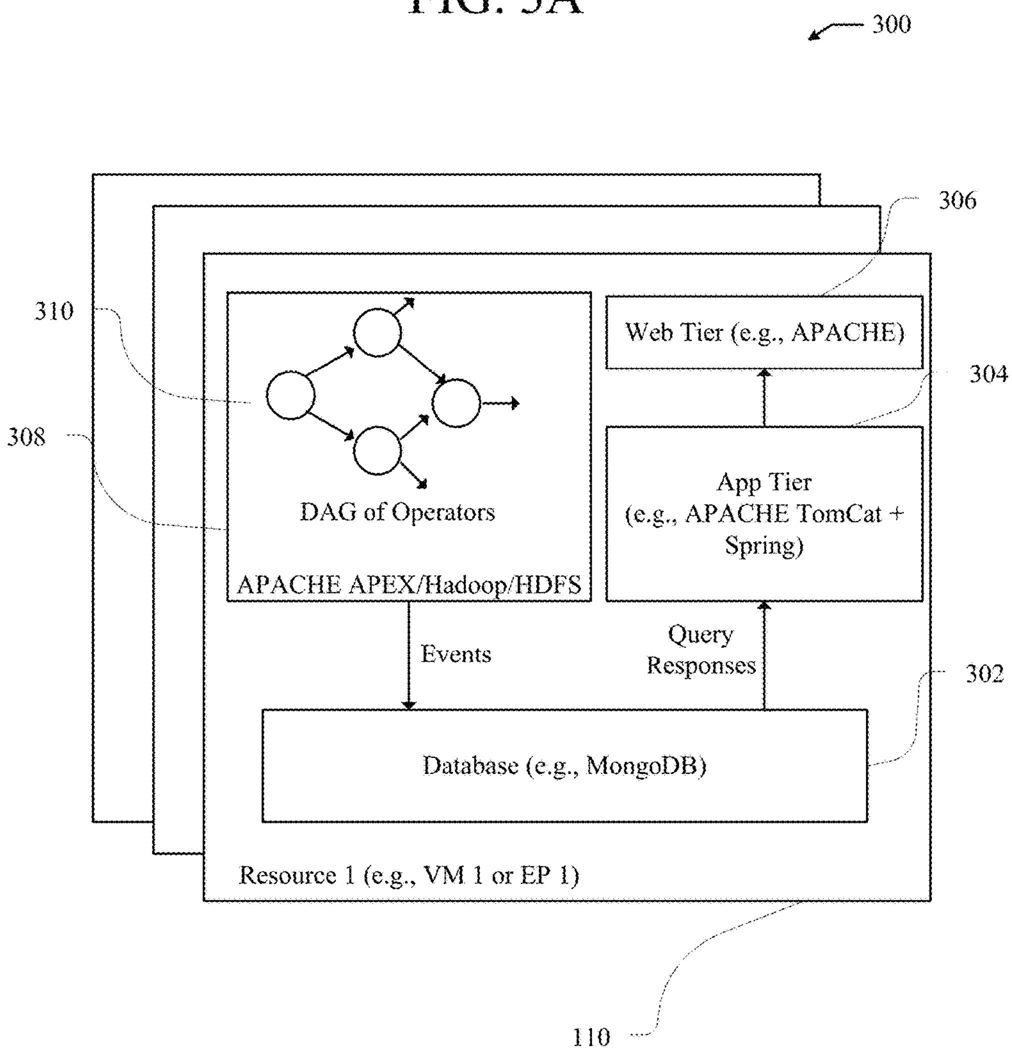
280
282
284
UNDERLAY
OVERLAY
TENANT
RESOURCES

FIG. 2D

FIG. 3A


300
306
310
308
304
302
110
Web Tier (e.g., APACHE)
App Tier
(e.g., APACHE TomCat +
Spring)
DAG of Operators
APACHE APEX/Hadoop/HDFS
Events
Query
Responses
Database (e.g., MongoDB)
Resource 1 (e.g., VM 1 or EP 1)

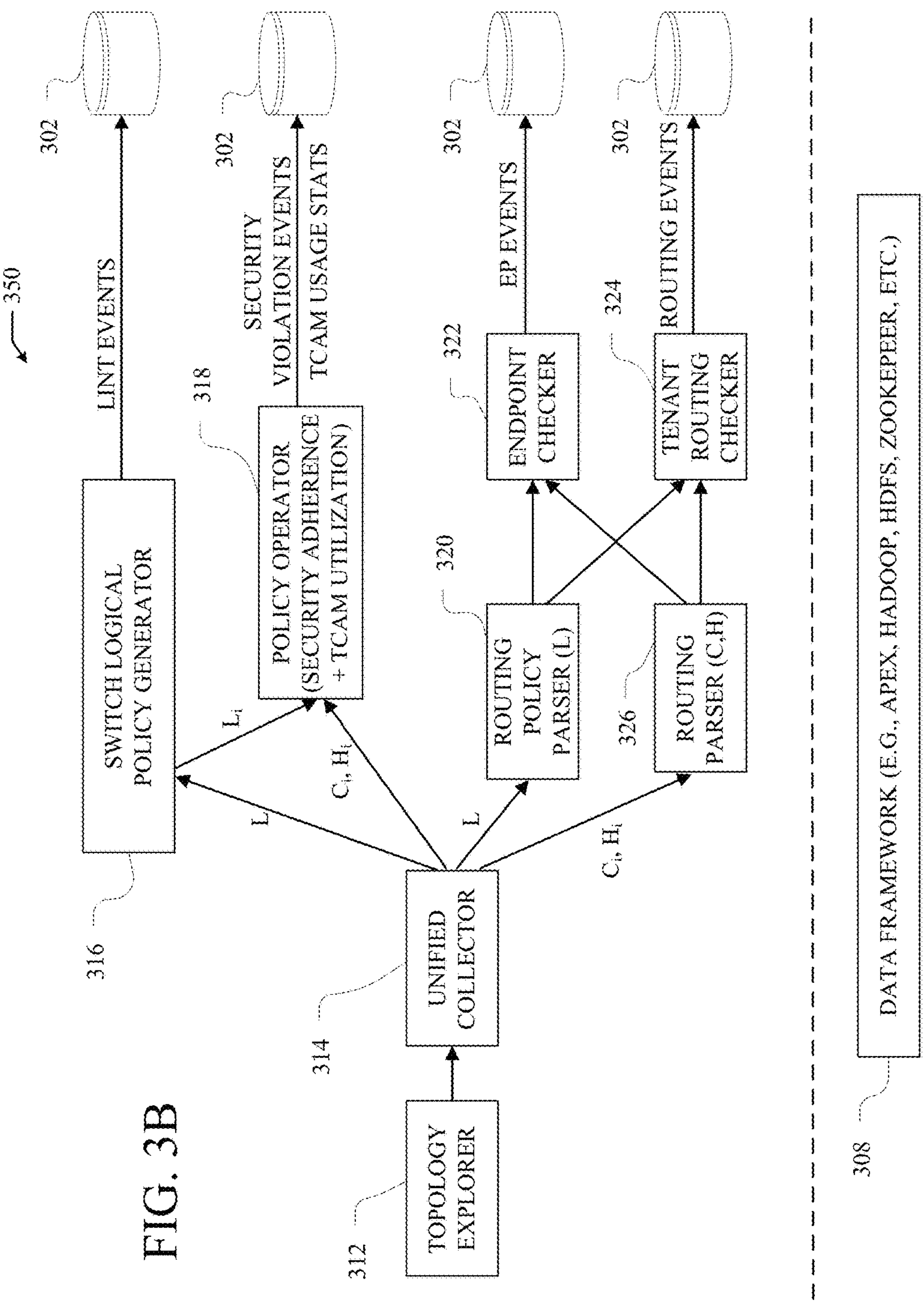
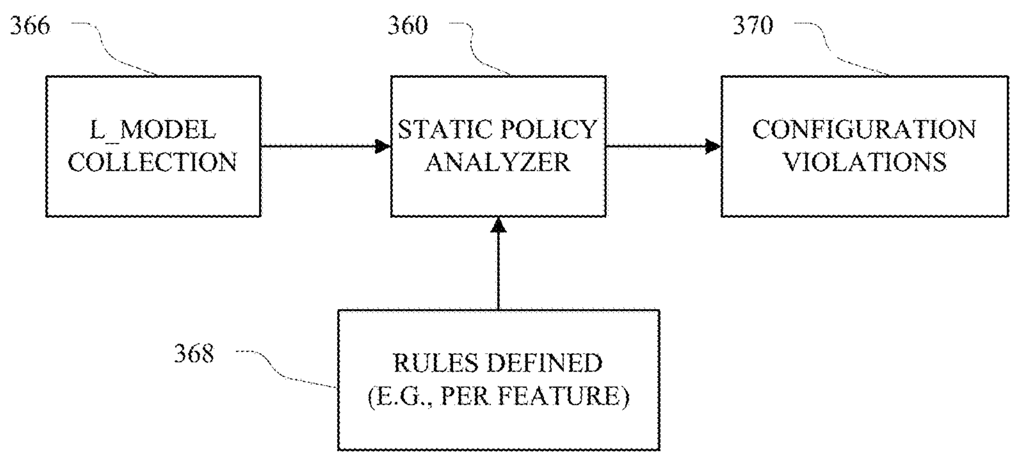

350
TOPOLOGY EXPLORER
312
UNIFIED COLLECTOR
314
SWITCH LOGICAL POLICY GENERATOR
316
POLICY OPERATOR (SECURITY ADHERENCE + TCAM UTILIZATION)
318
ROUTING POLICY PARSER (L)
320
ROUTING PARSER (C,H)
326
ENDPOINT CHECKER
322
TENANT ROUTING CHECKER
324
L
L
L_i
C_i, H_i
C_i, H_i
LINT EVENTS
SECURITY VIOLATION EVENTS
TCAM USAGE STATS
EP EVENTS
ROUTING EVENTS
302
302
302
302
DATA FRAMEWORK (E.G., APEX, HADOOP, HDFS, ZOOKEPEER, ETC.)
308

FIG. 3B

FIG. 3C

INPUT AND OUTPUT OF STATIC POLICY ANALYZER



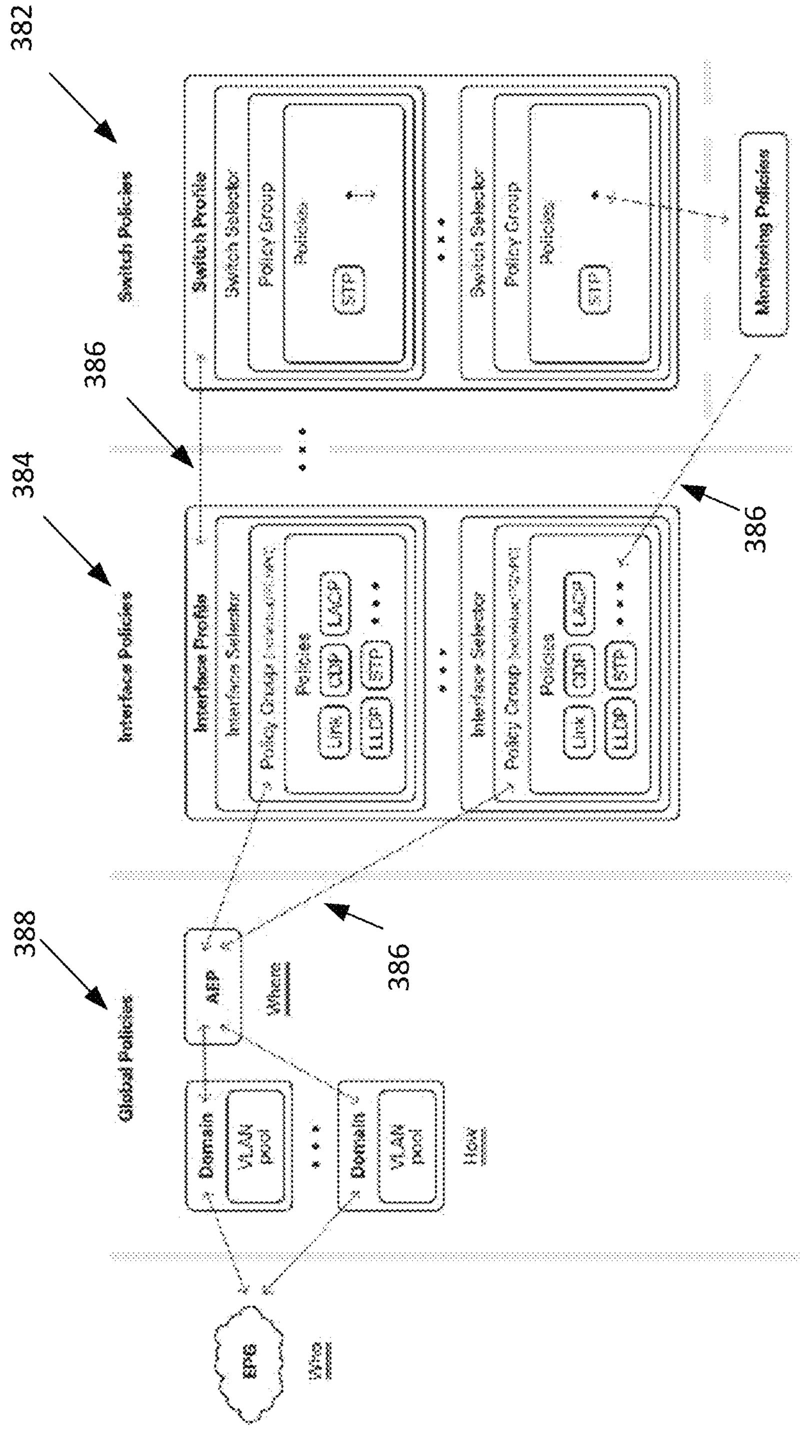

382
384
386
388
Switch Policies
Interface Policies
Global Policies
Switch Profile
Switch Selector
Policy Group
Policies
STP
Monitoring Policies
Interface Profile
Interface Selector
Link
CDP
LACP
LLDP
Domain
VLAN pool
AEP
EPG
Where
How
Who

FIG. 3D

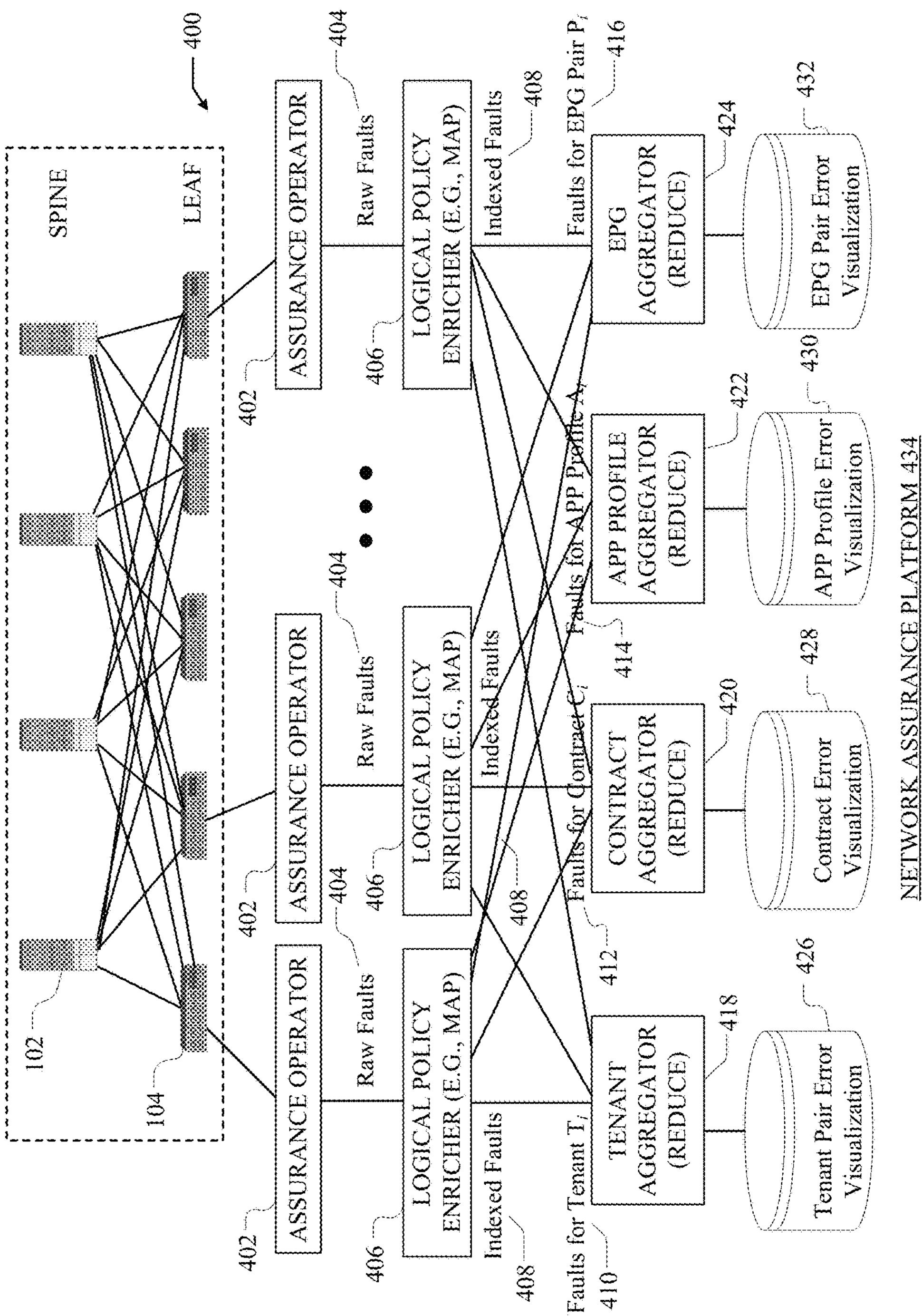

400
SPINE
LEAF
102
104
ASSURANCE OPERATOR
402
Raw Faults
404
LOGICAL POLICY ENRICHER (E.G., MAP)
406
Indexed Faults
408
Faults for Tenant T_i
410
Faults for Contract C_i
412
Faults for APP Profile A_i
414
Faults for EPG Pair P_i
416
TENANT AGGREGATOR (REDUCE)
418
CONTRACT AGGREGATOR (REDUCE)
420
APP PROFILE AGGREGATOR (REDUCE)
422
EPG AGGREGATOR (REDUCE)
424
Tenant Pair Error Visualization
426
Contract Error Visualization
428
APP Profile Error Visualization
430
EPG Pair Error Visualization
432
NETWORK ASSURANCE PLATFORM 434

FIG. 4

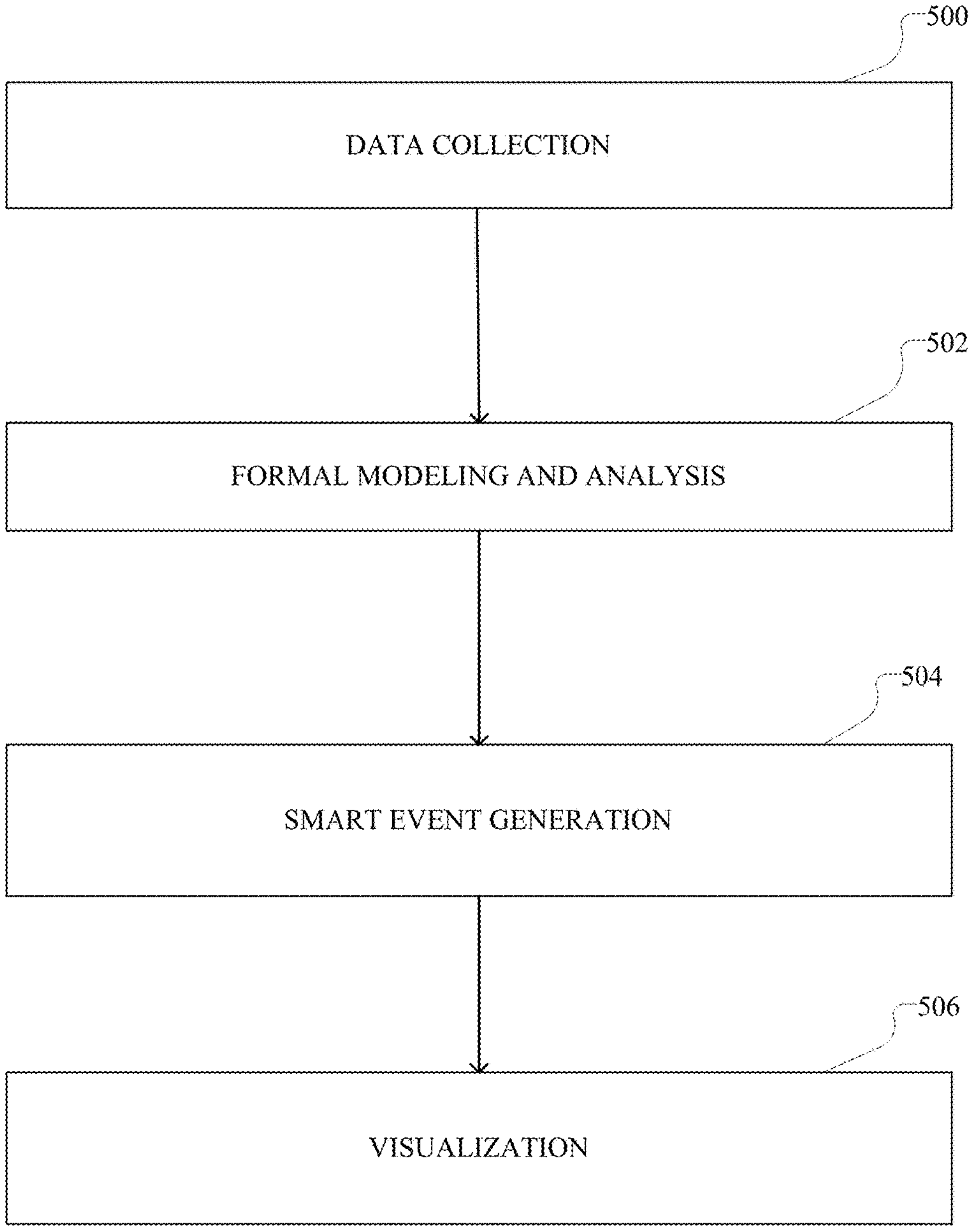

500
DATA COLLECTION
502
FORMAL MODELING AND ANALYSIS
504
SMART EVENT GENERATION
506
VISUALIZATION

FIG. 5A

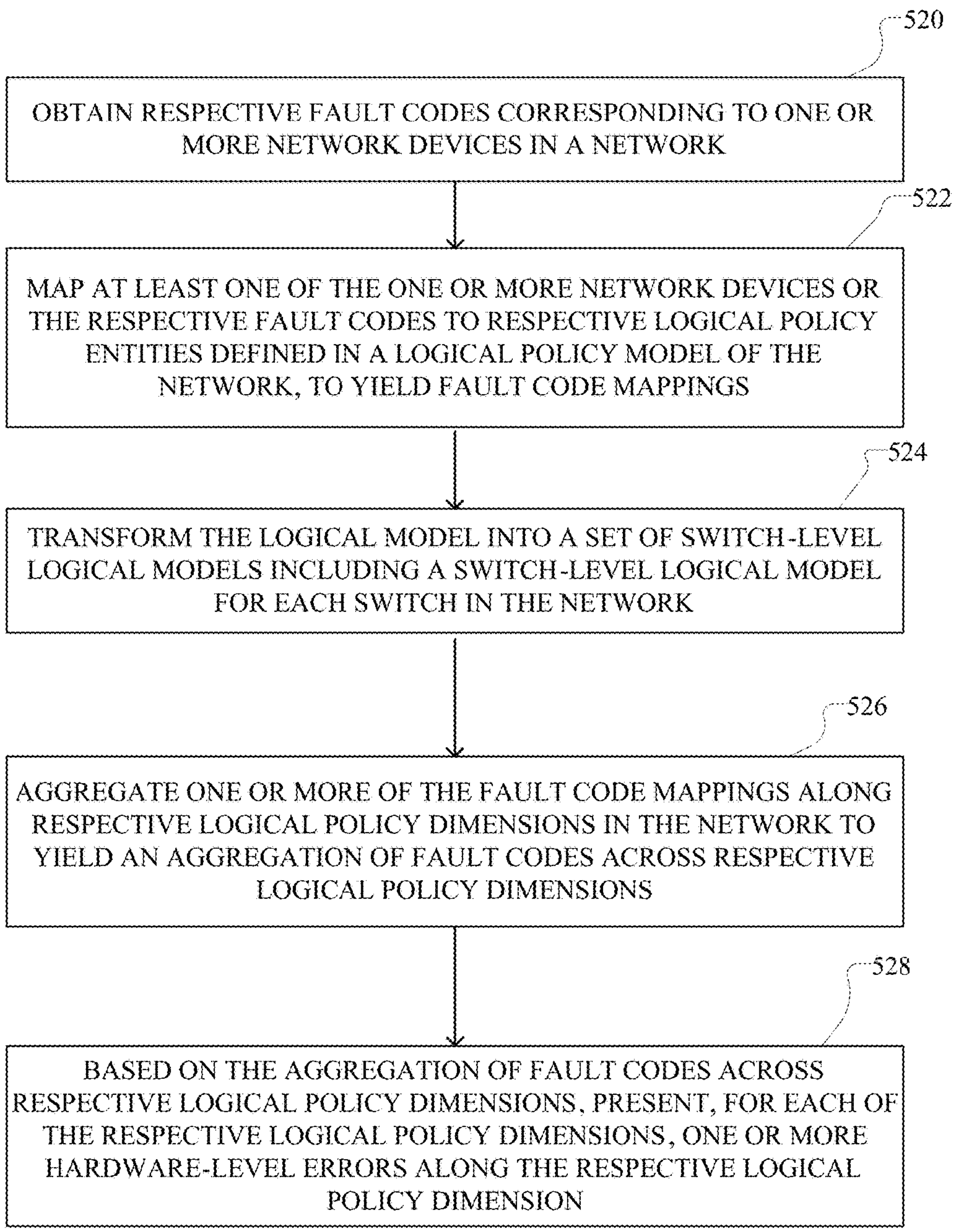

520
OBTAIN RESPECTIVE FAULT CODES CORRESPONDING TO ONE OR MORE NETWORK DEVICES IN A NETWORK
522
MAP AT LEAST ONE OF THE ONE OR MORE NETWORK DEVICES OR THE RESPECTIVE FAULT CODES TO RESPECTIVE LOGICAL POLICY ENTITIES DEFINED IN A LOGICAL POLICY MODEL OF THE NETWORK, TO YIELD FAULT CODE MAPPINGS
524
TRANSFORM THE LOGICAL MODEL INTO A SET OF SWITCH-LEVEL LOGICAL MODELS INCLUDING A SWITCH-LEVEL LOGICAL MODEL FOR EACH SWITCH IN THE NETWORK
526
AGGREGATE ONE OR MORE OF THE FAULT CODE MAPPINGS ALONG RESPECTIVE LOGICAL POLICY DIMENSIONS IN THE NETWORK TO YIELD AN AGGREGATION OF FAULT CODES ACROSS RESPECTIVE LOGICAL POLICY DIMENSIONS
528
BASED ON THE AGGREGATION OF FAULT CODES ACROSS RESPECTIVE LOGICAL POLICY DIMENSIONS, PRESENT, FOR EACH OF THE RESPECTIVE LOGICAL POLICY DIMENSIONS, ONE OR MORE HARDWARE-LEVEL ERRORS ALONG THE RESPECTIVE LOGICAL POLICY DIMENSION

FIG. 5B

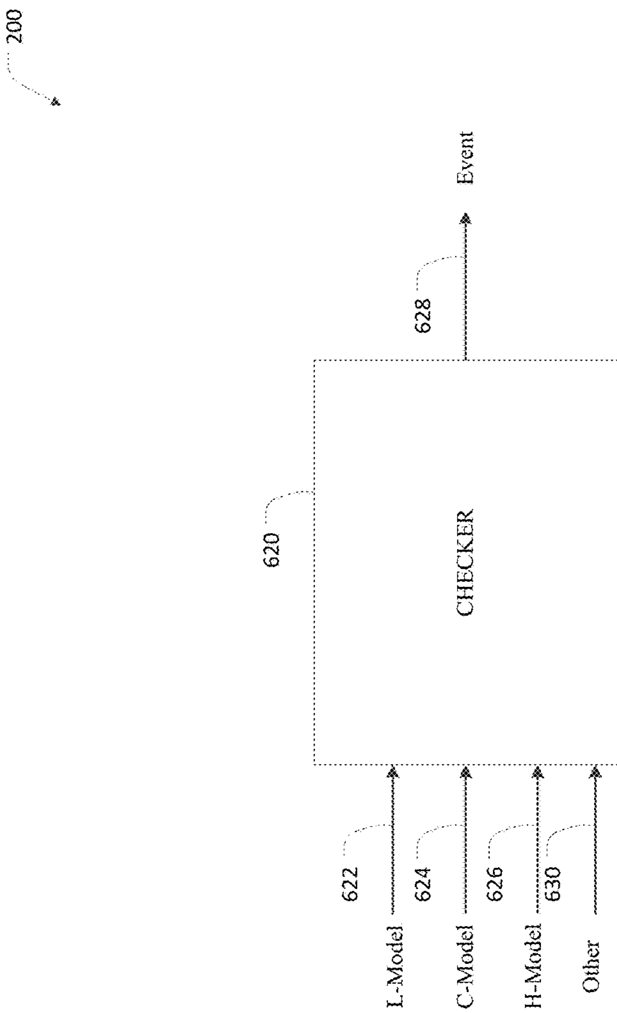

200
Event
628
620
CHECKER
622
624
626
630
L-Model
C-Model
H-Model
Other

FIG. 6

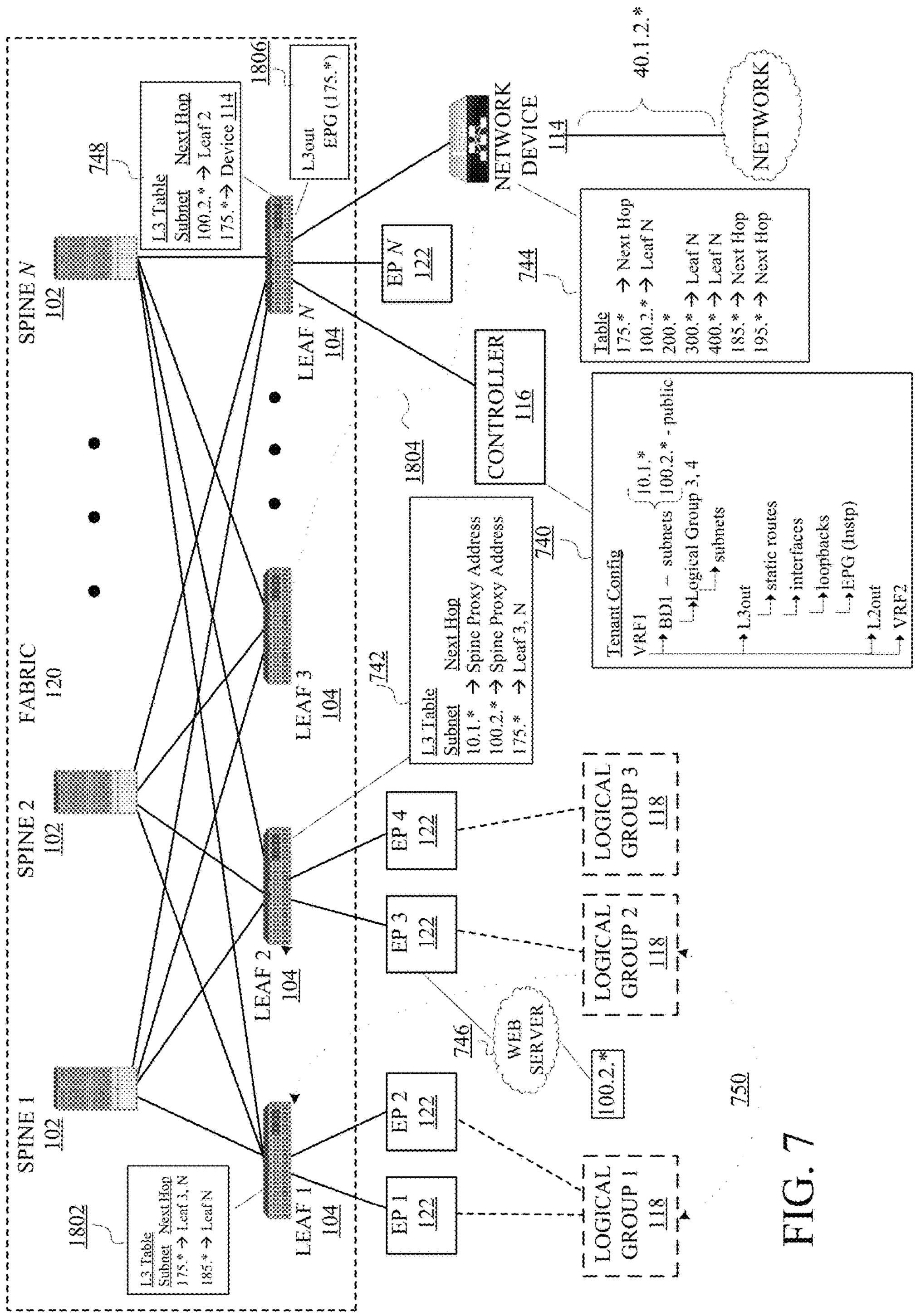

700
FABRIC
120
SPINE 1
102
SPINE 2
102
SPINE N
102
LEAF 1
104
LEAF 2
104
LEAF 3
104
LEAF N
104
1802
L3 Table
Subnet Next Hop
175.* → Leaf 3, N
185.* → Leaf N
748
L3 Table
Subnet Next Hop
100.2.* → Leaf 2
175.* → Device 114
1806
L3out
EPG (175.*)
742
L3 Table
Subnet Next Hop
10.1.* → Spine Proxy Address
100.2.* → Spine Proxy Address
175.* → Leaf 3, N
1804
EP 1
122
EP 2
122
EP 3
122
EP 4
122
EP N
122
CONTROLLER
116
NETWORK DEVICE
114
40.1.2.*
NETWORK
744
Table
175.* → Next Hop
100.2.* → Leaf N
200.*
300.* → Leaf N
400.* → Leaf N
185.* → Next Hop
195.* → Next Hop
740
Tenant Config
VRF1
BD1 – subnets
10.1.*
100.2.* - public
Logical Group 3, 4
subnets
L3out
static routes
interfaces
loopbacks
EPG (Instp)
L2out
VRF2
746
WEB SERVER
100.2.*
LOGICAL GROUP 1
118
LOGICAL GROUP 2
118
LOGICAL GROUP 3
118
750

FIG. 7

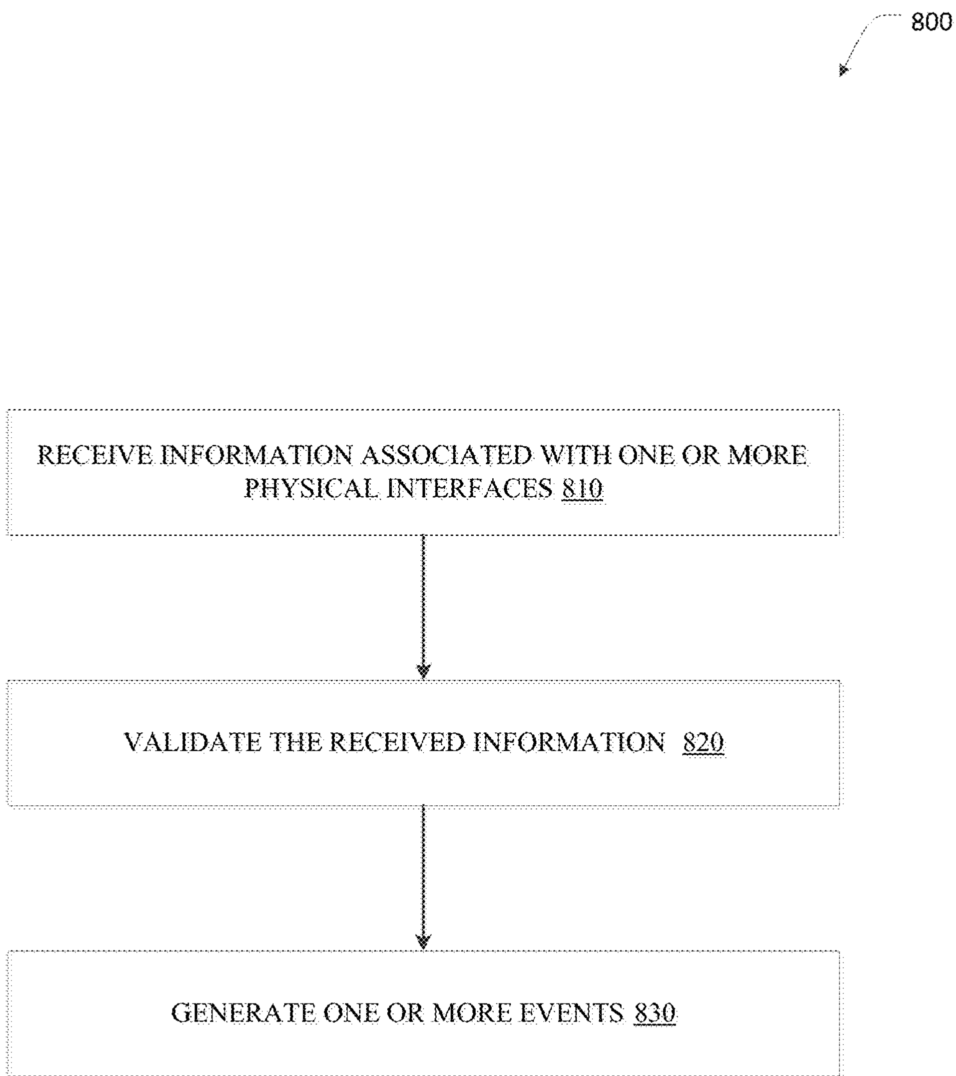

800
RECEIVE INFORMATION ASSOCIATED WITH ONE OR MORE PHYSICAL INTERFACES 810
VALIDATE THE RECEIVED INFORMATION 820
GENERATE ONE OR MORE EVENTS 830

FIG. 8

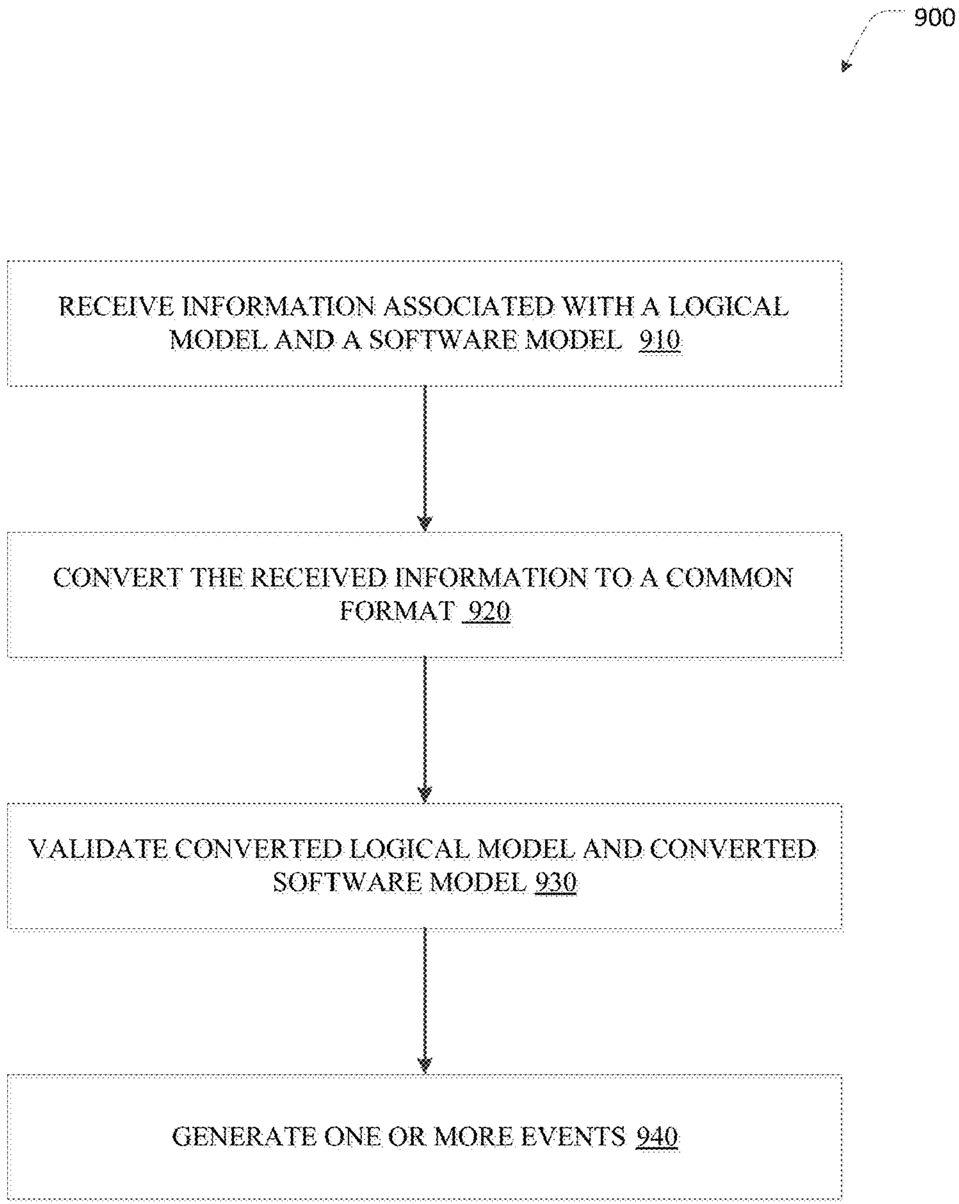

900
RECEIVE INFORMATION ASSOCIATED WITH A LOGICAL MODEL AND A SOFTWARE MODEL 910
CONVERT THE RECEIVED INFORMATION TO A COMMON FORMAT 920
VALIDATE CONVERTED LOGICAL MODEL AND CONVERTED SOFTWARE MODEL 930
GENERATE ONE OR MORE EVENTS 940

FIG. 9

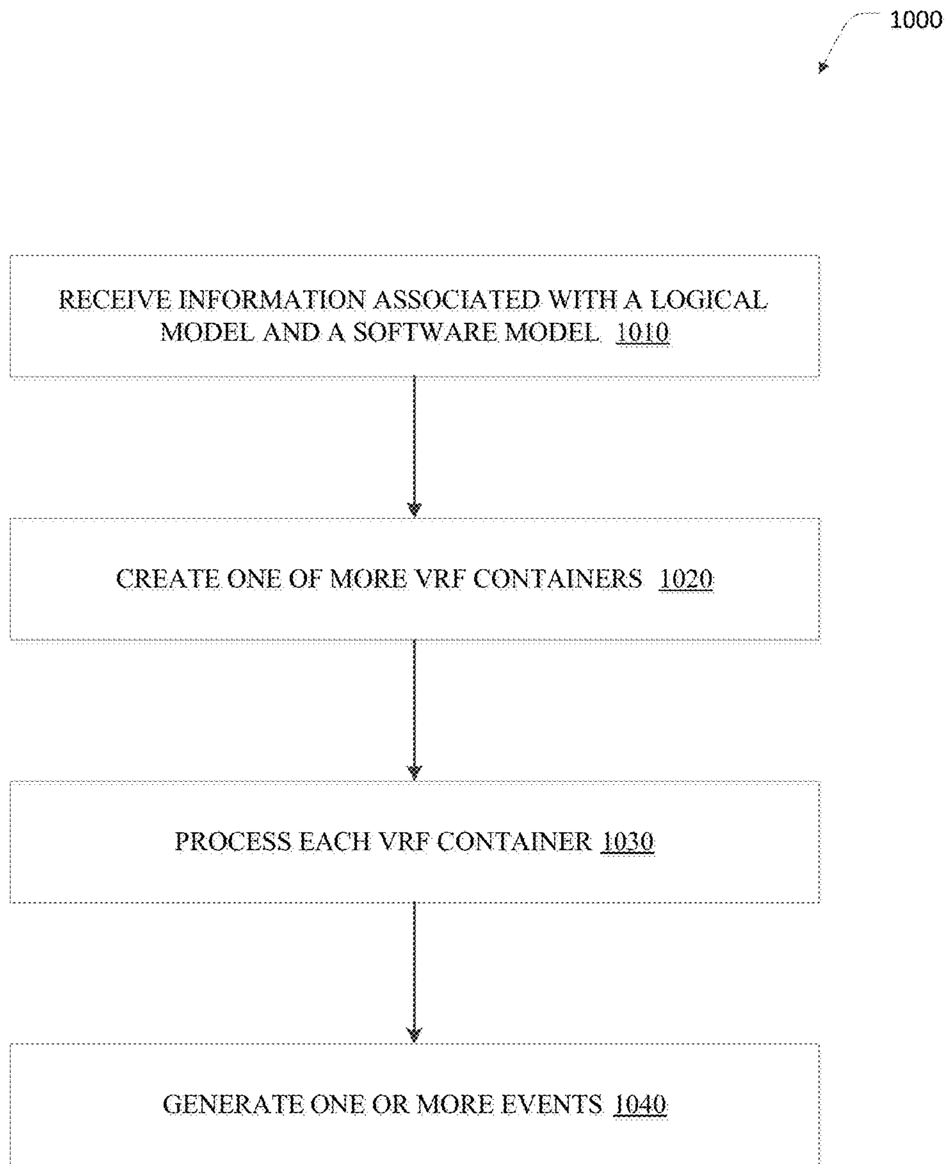

1000
RECEIVE INFORMATION ASSOCIATED WITH A LOGICAL MODEL AND A SOFTWARE MODEL 1010
CREATE ONE OF MORE VRF CONTAINERS 1020
PROCESS EACH VRF CONTAINER 1030
GENERATE ONE OR MORE EVENTS 1040

FIG. 10

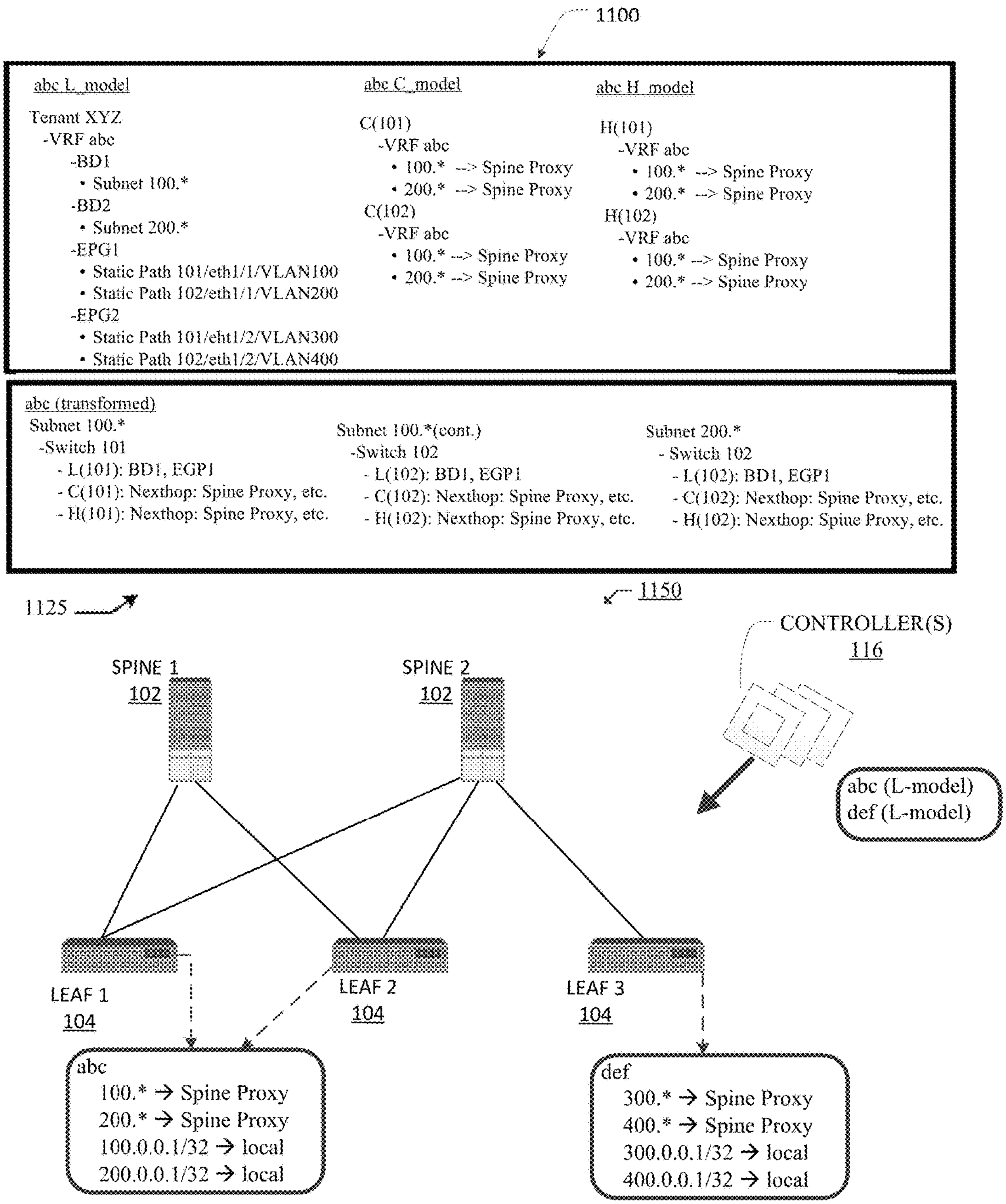

1100
abc L_model
Tenant XYZ
-VRF abc
-BD1
• Subnet 100.*
-BD2
• Subnet 200.*
-EPG1
• Static Path 101/eth1/1/VLAN100
• Static Path 102/eth1/1/VLAN200
-EPG2
• Static Path 101/eht1/2/VLAN300
• Static Path 102/eth1/2/VLAN400
abc C_model
C(101)
-VRF abc
• 100.* --> Spine Proxy
• 200.* --> Spine Proxy
C(102)
-VRF abc
• 100.* --> Spine Proxy
• 200.* --> Spine Proxy
abc H_model
H(101)
-VRF abc
• 100.* --> Spine Proxy
• 200.* --> Spine Proxy
H(102)
-VRF abc
• 100.* --> Spine Proxy
• 200.* --> Spine Proxy
abc (transformed)
Subnet 100.*
-Switch 101
- L(101): BD1, EGP1
- C(101): Nexthop: Spine Proxy, etc.
- H(101): Nexthop: Spine Proxy, etc.
Subnet 100.*(cont.)
-Switch 102
- L(102): BD1, EGP1
- C(102): Nexthop: Spine Proxy, etc.
- H(102): Nexthop: Spine Proxy, etc.
Subnet 200.*
- Switch 102
- L(102): BD1, EGP1
- C(102): Nexthop: Spine Proxy, etc.
- H(102): Nexthop: Spine Proxy, etc.
1125
1150
CONTROLLER(S)
116
SPINE 1
102
SPINE 2
102
abc (L-model)
def (L-model)
LEAF 1
104
LEAF 2
104
LEAF 3
104
abc
100.* → Spine Proxy
200.* → Spine Proxy
100.0.0.1/32 → local
200.0.0.1/32 → local
def
300.* → Spine Proxy
400.* → Spine Proxy
300.0.0.1/32 → local
400.0.0.1/32 → local

FIG. 11

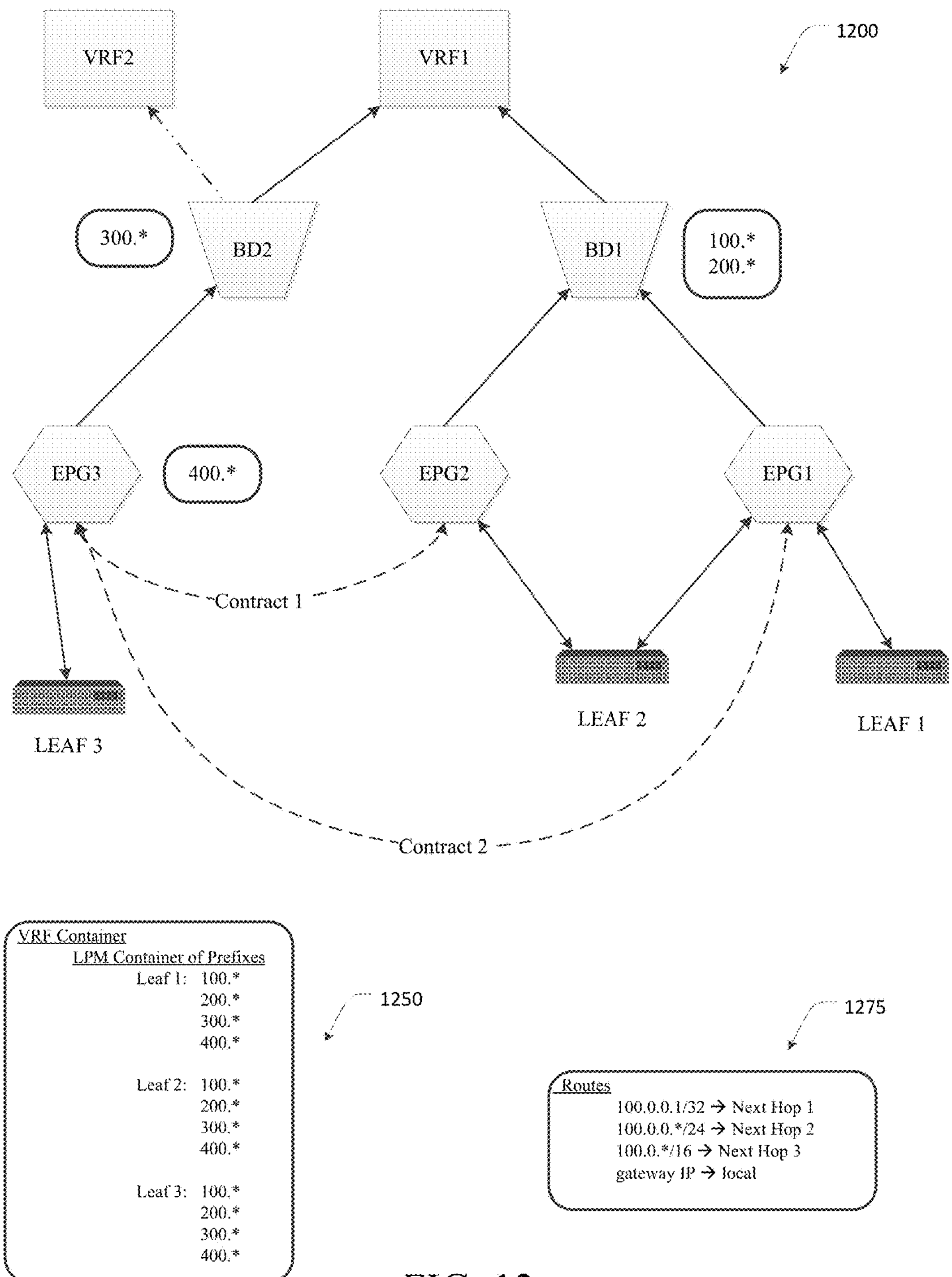
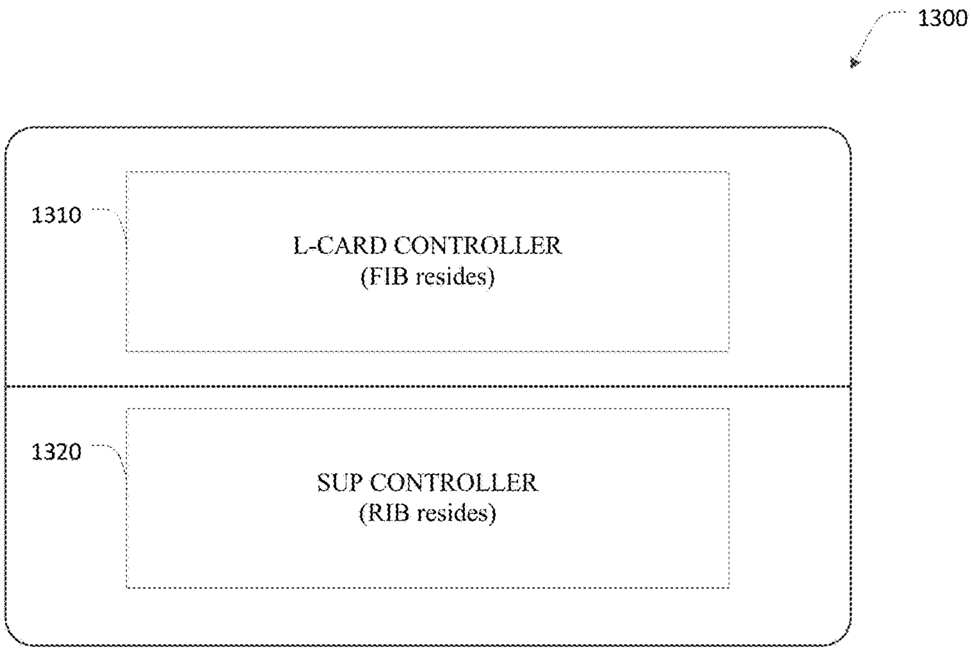

1200
VRF2
VRF1
300.*
BD2
BD1
100.*
200.*
EPG3
400.*
EPG2
EPG1
Contract 1
LEAF 3
LEAF 2
LEAF 1
Contract 2
VRF Container
LPM Container of Prefixes
Leaf 1: 100.*
200.*
300.*
400.*
Leaf 2: 100.*
200.*
300.*
400.*
Leaf 3: 100.*
200.*
300.*
400.*
1250
1275
Routes
100.0.0.1/32 → Next Hop 1
100.0.0.*/24 → Next Hop 2
100.0.*/16 → Next Hop 3
gateway IP → local

FIG. 12


1300
1310
L-CARD CONTROLLER
(FIB resides)
1320
SUP CONTROLLER
(RIB resides)

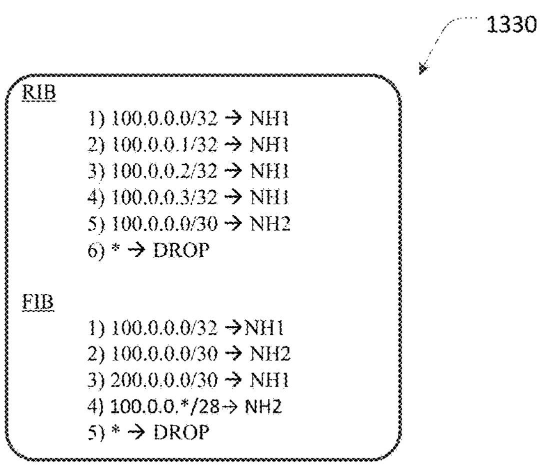

1330
RIB
1) 100.0.0.0/32 → NH1
2) 100.0.0.1/32 → NH1
3) 100.0.0.2/32 → NH1
4) 100.0.0.3/32 → NH1
5) 100.0.0.0/30 → NH2
6) * → DROP
FIB
1) 100.0.0.0/32 →NH1
2) 100.0.0.0/30 → NH2
3) 200.0.0.0/30 → NH1
4) 100.0.0.*/28→ NH2
5) * → DROP

FIG. 13

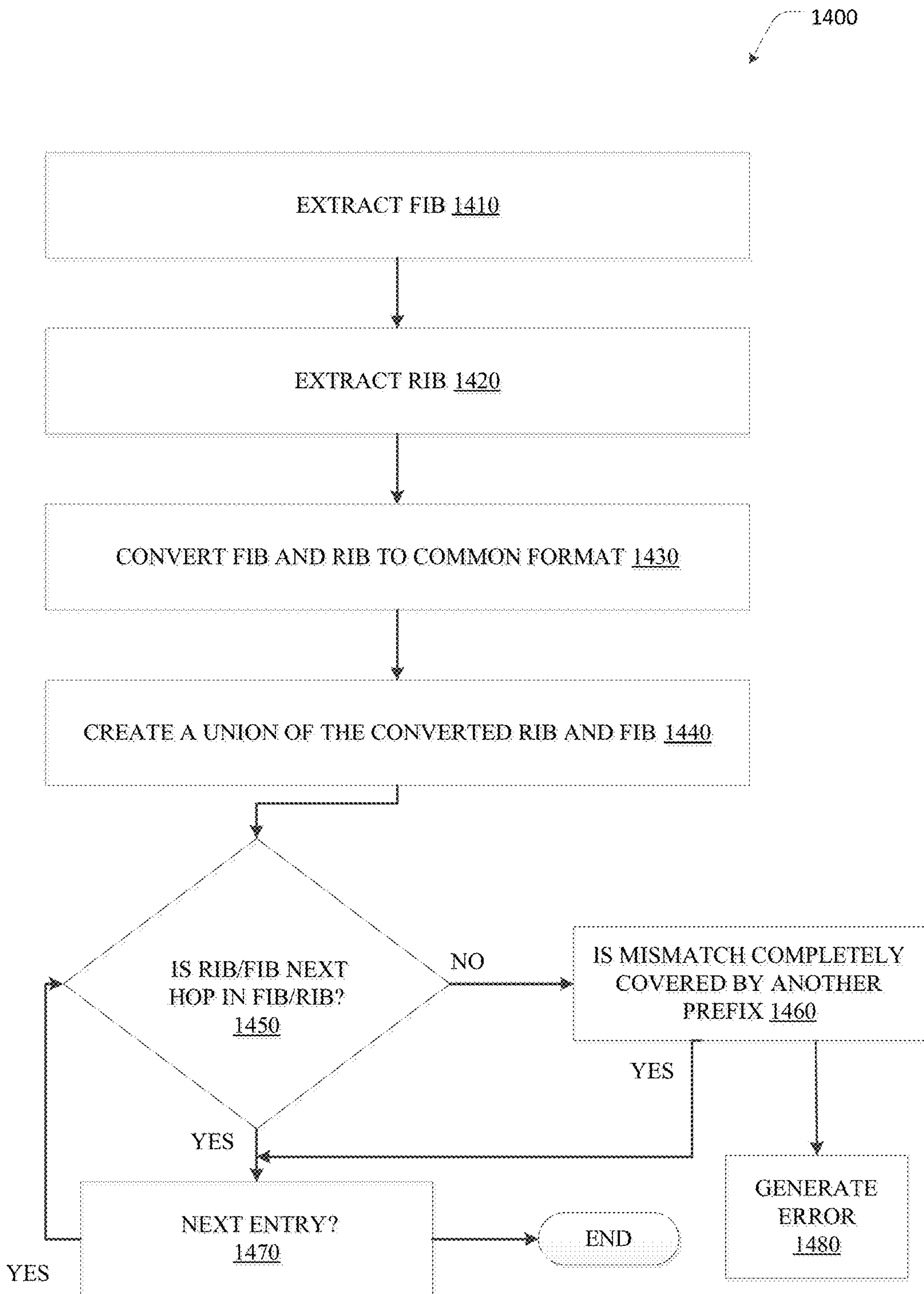

1400
EXTRACT FIB 1410
EXTRACT RIB 1420
CONVERT FIB AND RIB TO COMMON FORMAT 1430
CREATE A UNION OF THE CONVERTED RIB AND FIB 1440
IS RIB/FIB NEXT HOP IN FIB/RIB? 1450
NO
IS MISMATCH COMPLETELY COVERED BY ANOTHER PREFIX 1460
YES
YES
NEXT ENTRY? 1470
END
GENERATE ERROR 1480
YES

FIG. 14

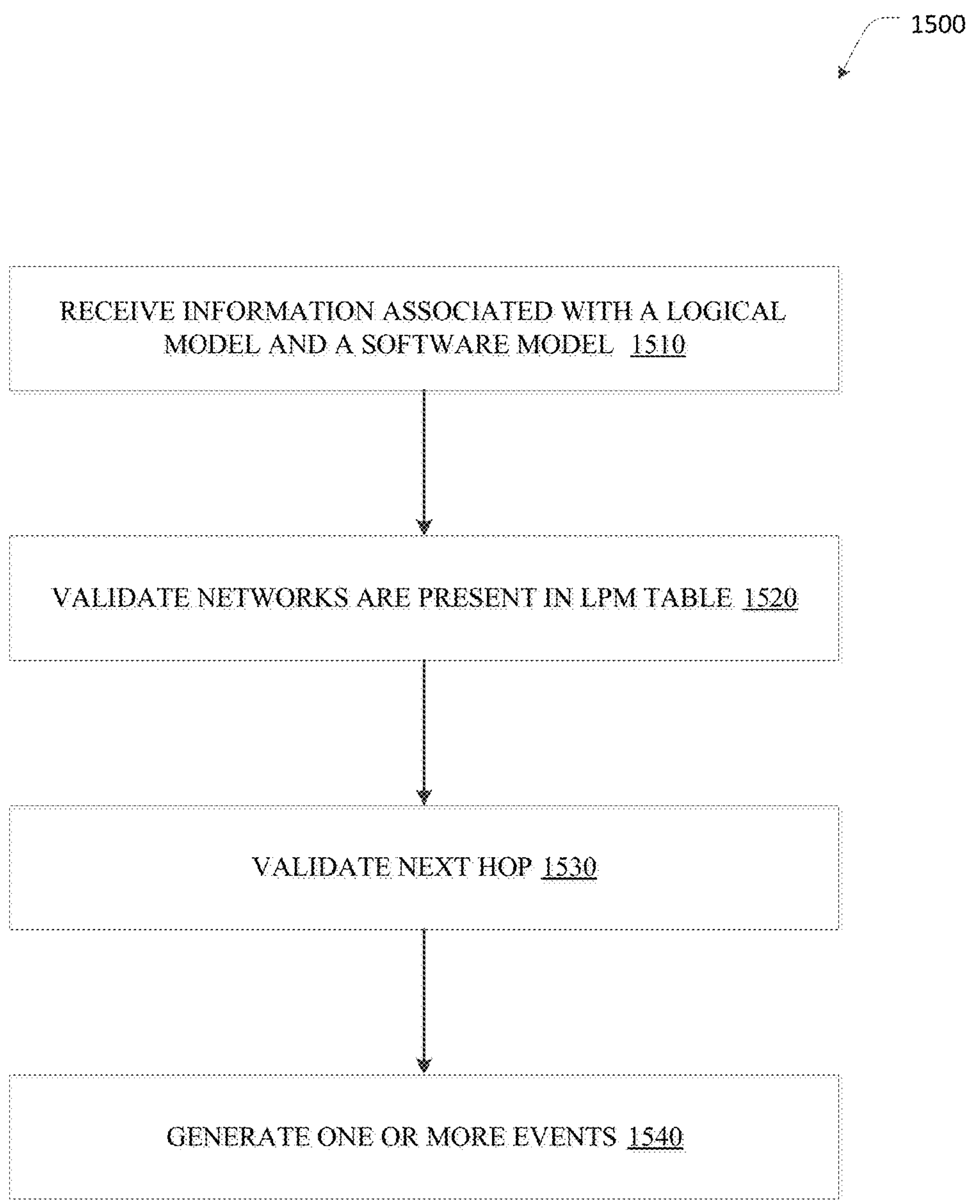

1500
RECEIVE INFORMATION ASSOCIATED WITH A LOGICAL MODEL AND A SOFTWARE MODEL 1510
VALIDATE NETWORKS ARE PRESENT IN LPM TABLE 1520
VALIDATE NEXT HOP 1530
GENERATE ONE OR MORE EVENTS 1540

FIG. 15

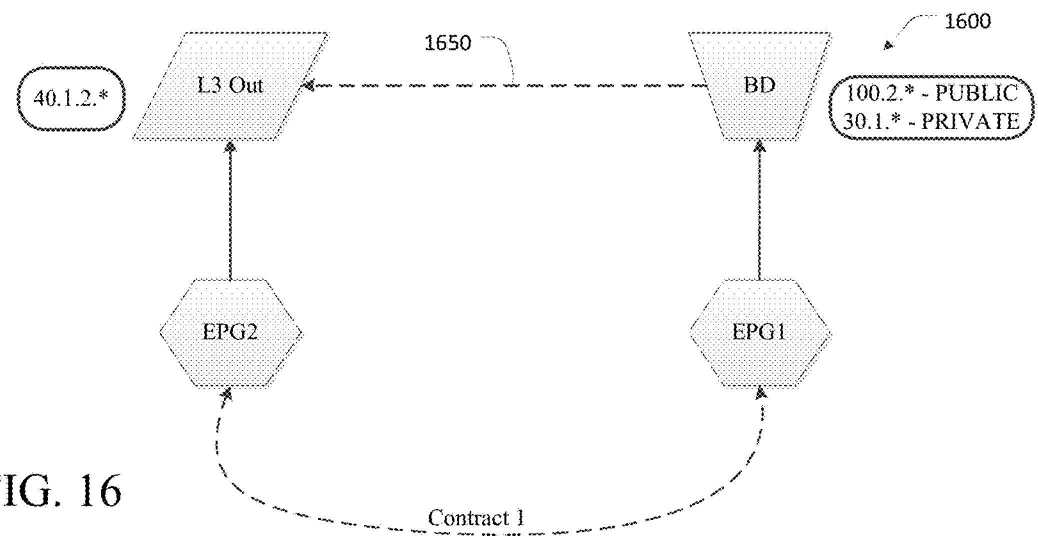

1600
1650
40.1.2.*
L3 Out
BD
100.2.* - PUBLIC
30.1.* - PRIVATE
EPG2
EPG1
Contract 1

FIG. 16

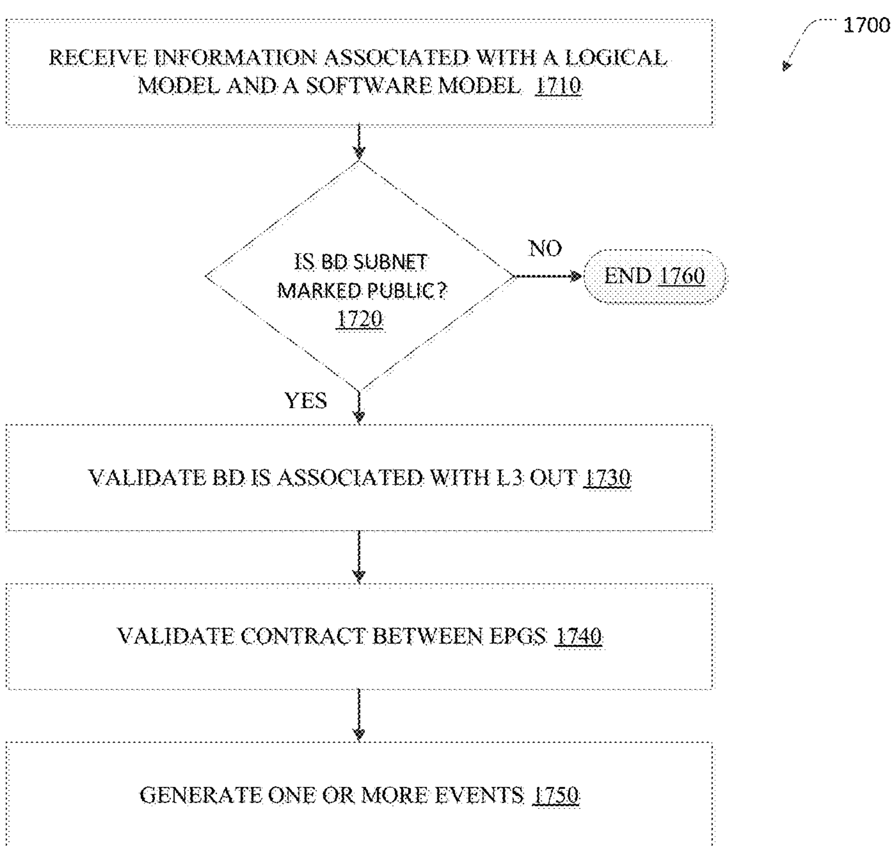

1700
RECEIVE INFORMATION ASSOCIATED WITH A LOGICAL MODEL AND A SOFTWARE MODEL 1710
IS BD SUBNET MARKED PUBLIC? 1720
NO
END 1760
YES
VALIDATE BD IS ASSOCIATED WITH L3 OUT 1730
VALIDATE CONTRACT BETWEEN EPGS 1740
GENERATE ONE OR MORE EVENTS 1750

FIG. 17

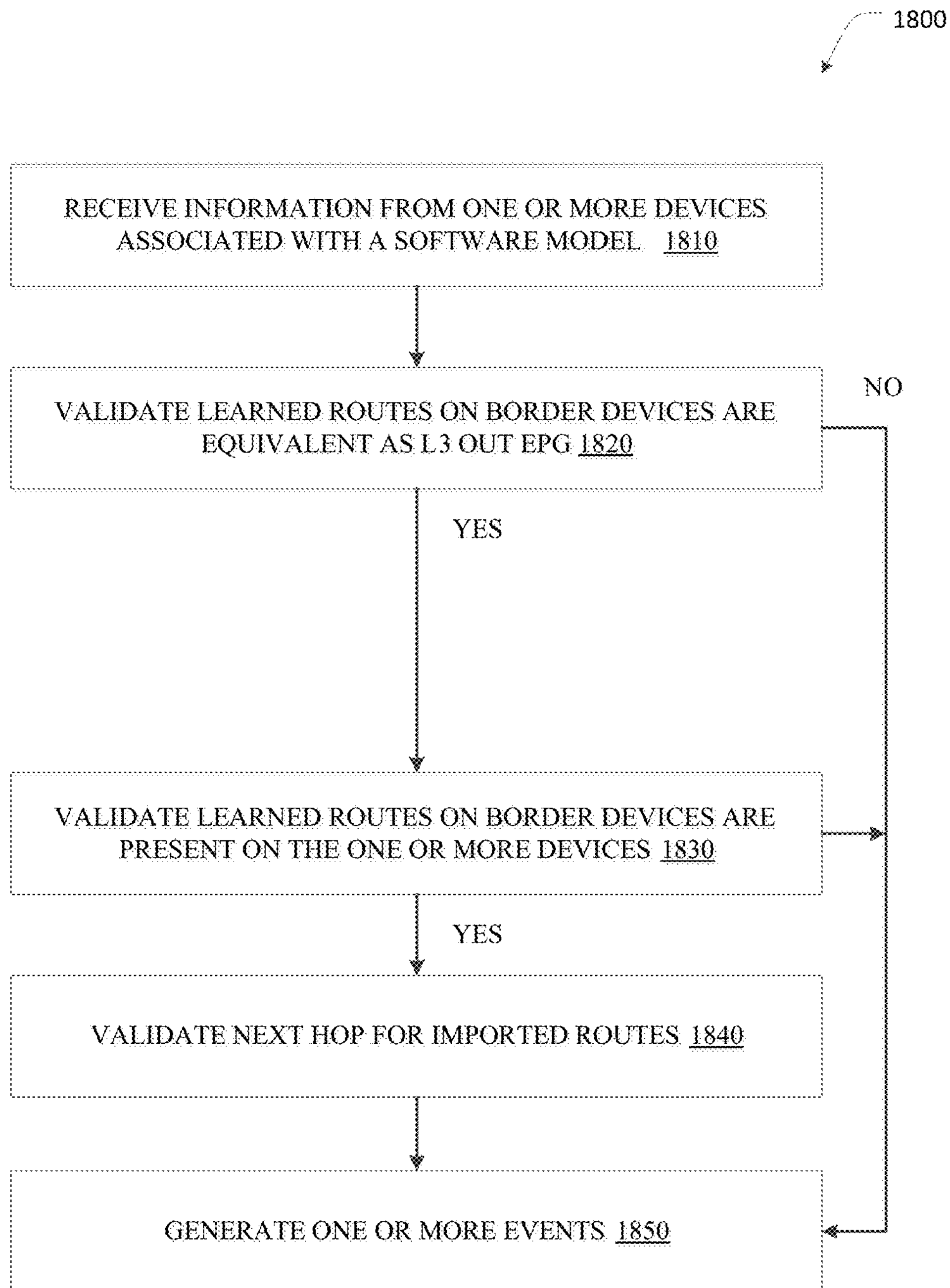

1800
RECEIVE INFORMATION FROM ONE OR MORE DEVICES ASSOCIATED WITH A SOFTWARE MODEL 1810
VALIDATE LEARNED ROUTES ON BORDER DEVICES ARE EQUIVALENT AS L3 OUT EPG 1820
NO
YES
VALIDATE LEARNED ROUTES ON BORDER DEVICES ARE PRESENT ON THE ONE OR MORE DEVICES 1830
YES
VALIDATE NEXT HOP FOR IMPORTED ROUTES 1840
GENERATE ONE OR MORE EVENTS 1850

FIG. 18

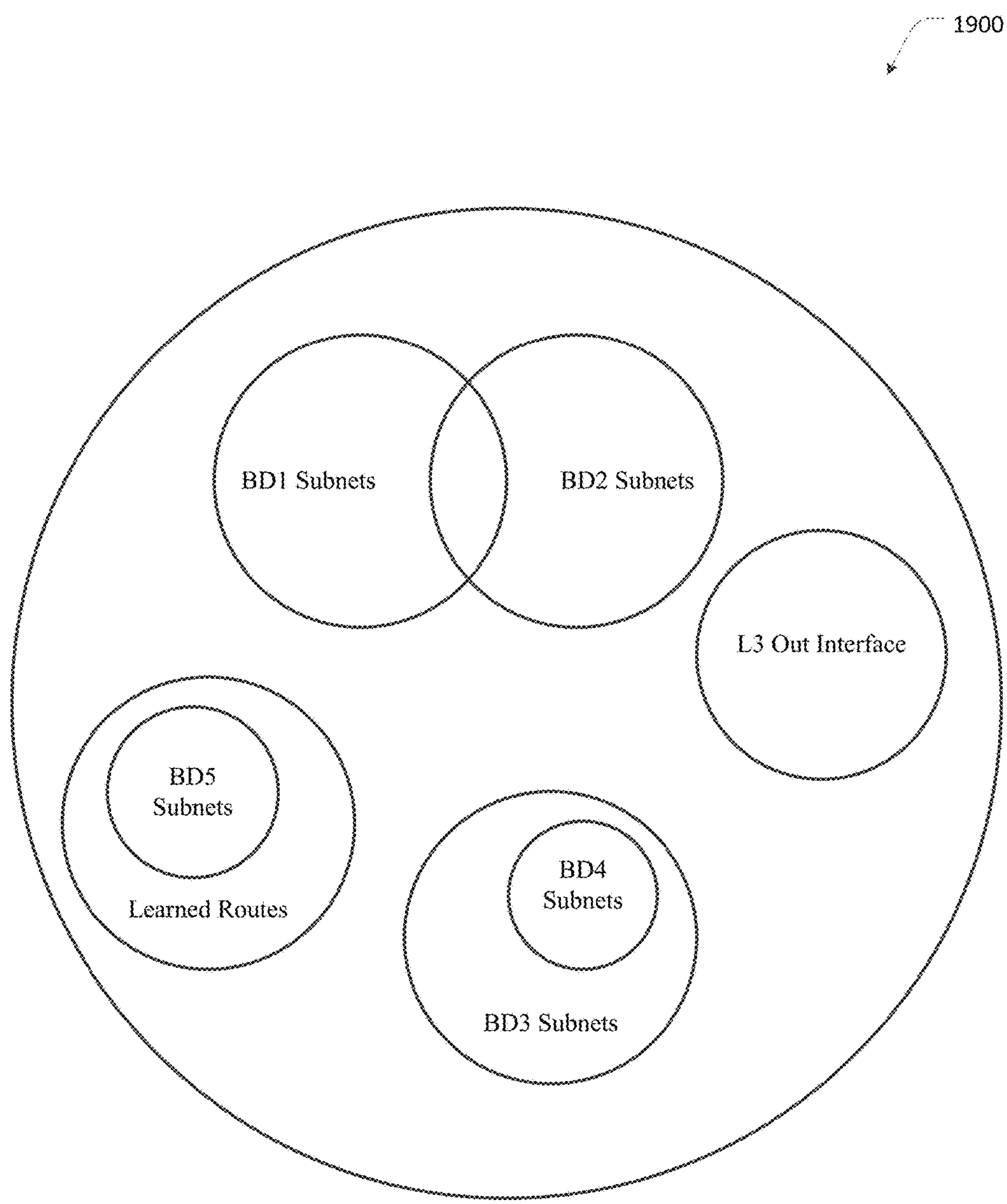

1900
BD1 Subnets
BD2 Subnets
L3 Out Interface
BD5
Subnets
Learned Routes
BD4
Subnets
BD3 Subnets

FIG. 19

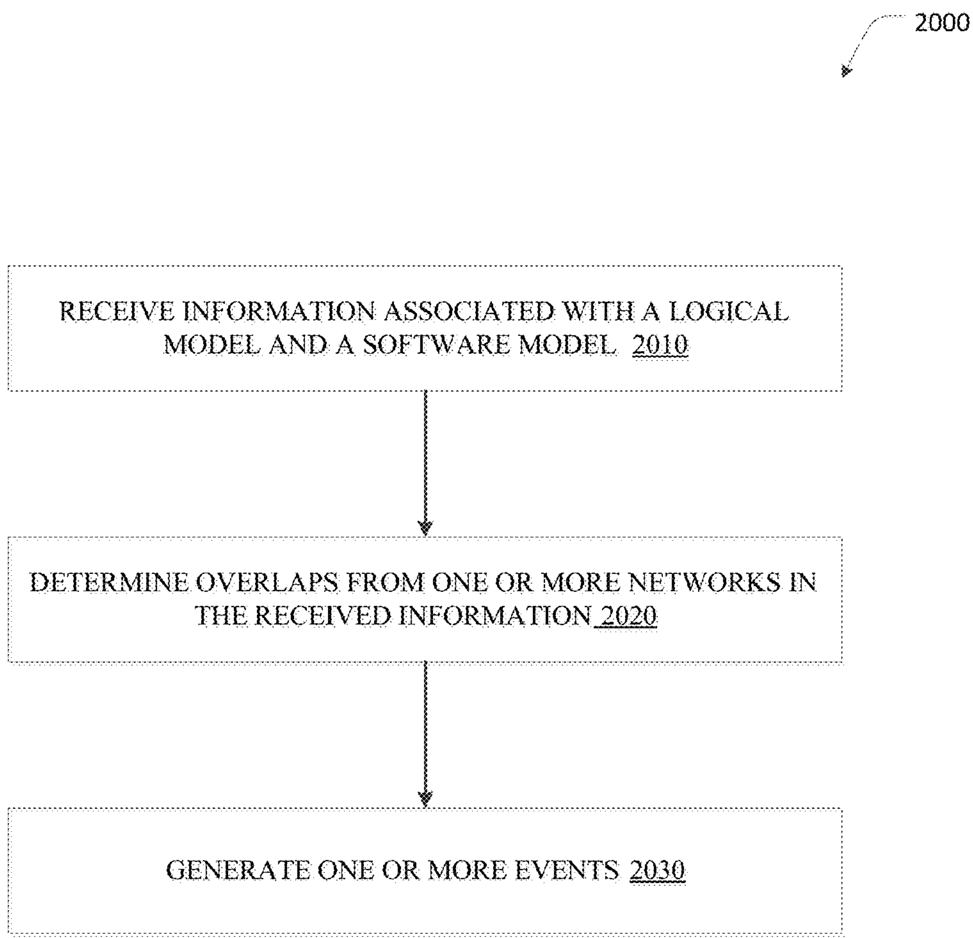

2000
RECEIVE INFORMATION ASSOCIATED WITH A LOGICAL MODEL AND A SOFTWARE MODEL 2010
DETERMINE OVERLAPS FROM ONE OR MORE NETWORKS IN THE RECEIVED INFORMATION 2020
GENERATE ONE OR MORE EVENTS 2030

FIG. 20

FIG. 21

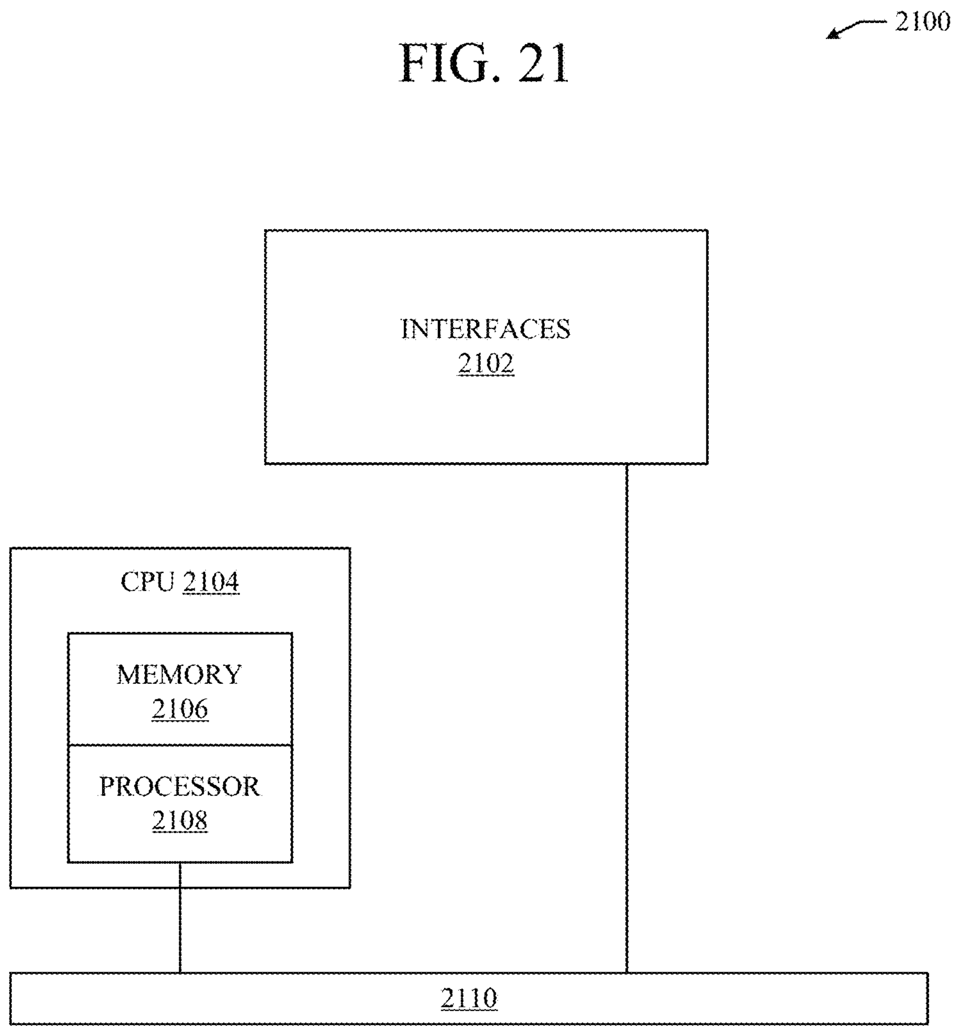
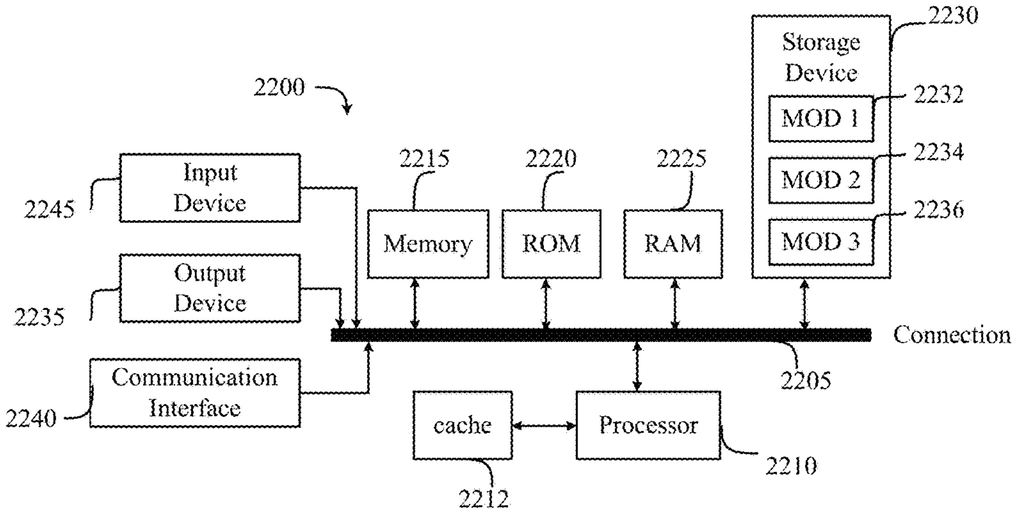

2100
INTERFACES
2102
CPU 2104
MEMORY
2106
PROCESSOR
2108
2110

FIG. 22


2200
Input Device
2245
Output Device
2235
Communication Interface
2240
2215
Memory
2220
ROM
2225
RAM
2230
Storage Device
MOD 1
2232
MOD 2
2234
MOD 3
2236
Connection
2205
cache
2212
Processor
2210

VALIDATION OF LAYER 3 BRIDGE DOMAIN SUBNETS IN IN A NETWORK

CROSS REFERENCE TO RELATED APPLICATIONS

The instant application claims priority to US. Provisional Application No. 62/521,779, entitled VALIDATION OF LAYER 3 BD SUBNETS IN A NETWORK, filed Jun. 19, 2017, the contents of which are incorporated by reference in its entirety.

TECHNICAL FIELD

The present technology pertains to network configuration and assurance, and more specifically to routing and forwarding configuration and assurance internal and external to a network.

BACKGROUND

Computer networks are becoming increasingly complex, often involving low level as well as high level configurations at various layers of the network. For example, computer networks generally include numerous access policies, forwarding policies, routing policies, security policies, quality-of-service (QoS) policies, etc., which together define the overall behavior and operation of the network. Network operators have a wide array of configuration options for tailoring the network to the needs of the users. While the different configuration options available provide network operators a great degree of flexibility and control over the network, they also add to the complexity of the network. In many cases, the configuration process can become highly complex. Not surprisingly, the network configuration process is increasingly error prone. In addition, troubleshooting errors in a highly complex network can be extremely difficult. The process of identifying the root cause of undesired behavior in the network can be a daunting task.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to describe the manner in which the above-recited and other advantages and features of the disclosure can be obtained, a more particular description of the principles briefly described above will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only exemplary embodiments of the disclosure and are not therefore to be considered to be limiting of its scope, the principles herein are described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIGS. **1**A and **1**B illustrate example network environments;

FIG. **2**A illustrates an example object model for a network;

FIG. **2**B illustrates an example object model for a tenant object in the example object model from FIG. **2**A;

FIG. **2**C illustrates an example association of various objects in the example object model from FIG. **2**A;

FIG. **2**D illustrates a schematic diagram of example models for implementing the example object model from FIG. **2**A;

FIG. **3**A illustrates an example network assurance appliance;

FIG. **3**B illustrates an example system for network assurance;

FIG. **3**C illustrates a schematic diagram of an example system for network assurance.

FIG. **3**D illustrates an example of validated policies;

FIG. **4** illustrates an example platform for distributed fault code aggregation;

FIGS. **5**A and **5**B illustrate example method embodiments for network assurance and fault code aggregation;

FIG. **6** illustrates an example checker of the network assurance appliance;

FIG. **7** illustrates an example network environment;

FIG. **8** illustrates an example method embodiment for network assurance of Layer 1 interfaces;

FIG. **9** illustrates an example method embodiment for network assurance of Layer 2 networking;

FIG. **10** illustrates an example method embodiment for network assurance of Layer 3 networking;

FIG. **11** illustrates an example configurations for network assurance;

FIG. **12** illustrates an example network environment and configuration for network assurance of Cross Logical Groups/VRFs;

FIG. **13** illustrates an example network environment and configuration for network assurance of the RIB and FIB;

FIG. **14** illustrates an example method embodiment for network assurance of the RIB and FIB;

FIG. **15** illustrates an example method embodiment for network assurance of Layer 3 out;

FIG. **16** illustrates an example network diagram for BD-L3out association;

FIG. **17** illustrates an example method embodiment for network assurance of BD-L3out association;

FIG. **18** illustrates an example method embodiment for network assurance of Learned Routes;

FIG. **19** illustrates an example diagram of subnet overlaps;

FIG. **20** illustrates an example method embodiment for network assurance of overlapping subnets;

FIG. **21** illustrates an example network device in accordance with various embodiments; and

FIG. **22** illustrates an example computing device in accordance with various embodiments.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Various embodiments of the disclosure are discussed in detail below. While specific implementations are discussed, it should be understood that this is done for illustration purposes only. A person skilled in the relevant art will recognize that other components and configurations may be used without parting from the spirit and scope of the disclosure. Thus, the following description and drawings are illustrative and are not to be construed as limiting. Numerous specific details are described to provide a thorough understanding of the disclosure. However, in certain instances, well-known or conventional details are not described in order to avoid obscuring the description. References to one or an embodiment in the present disclosure can be references to the same embodiment or any embodiment; and, such references mean at least one of the embodiments.

Reference to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the disclosure. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. Moreover, various features are described which may be exhibited by some embodiments and not by others.

The terms used in this specification generally have their ordinary meanings in the art, within the context of the disclosure, and in the specific context where each term is used. Alternative language and synonyms may be used for any one or more of the terms discussed herein, and no special significance should be placed upon whether or not a term is elaborated or discussed herein. In some cases, synonyms for certain terms are provided. A recital of one or more synonyms does not exclude the use of other synonyms. The use of examples anywhere in this specification including examples of any terms discussed herein is illustrative only, and is not intended to further limit the scope and meaning of the disclosure or of any example term. Likewise, the disclosure is not limited to various embodiments given in this specification.

Without intent to limit the scope of the disclosure, examples of instruments, apparatus, methods and their related results according to the embodiments of the present disclosure are given below. Note that titles or subtitles may be used in the examples for convenience of a reader, which in no way should limit the scope of the disclosure. Unless otherwise defined, technical and scientific terms used herein have the meaning as commonly understood by one of ordinary skill in the art to which this disclosure pertains. In the case of conflict, the present document, including definitions will control.

Additional features and advantages of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or can be learned by practice of the herein disclosed principles. The features and advantages of the disclosure can be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features of the disclosure will become more fully apparent from the following description and appended claims, or can be learned by the practice of the principles set forth herein.

Overview

Disclosed are systems, methods and non-transitory computer readable medium (CRM) for network assurance of a network. The systems, methods and non-transitory computer readable medium are configured to receive, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric and receive, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices. The systems, methods and non-transitory computer readable medium are also configured to create a local logical model in the first format, the local logical model being at least a portion of the received global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric, convert at least a portion of the created local logical model and at least a portion of the received software model into a common format, and compare content of overlapping fields from the common format of the local logical model and the common format of the software model, wherein a positive outcome of the comparison represents that the one or more network devices accurately created the received software model from the received global logical model. In some examples, the first and second formats are different from each other, the common format is one of the first and second formats, or is different from both of the first and second formats.

In some examples, the systems, methods and CRM can be configured to receive from the one or more network devices within the fabric, a hardware model of hardware configurations converted from the software model. The systems, methods and CRM can be configured to convert at least a portion of the received software model and at least a portion of the received hardware model into the common format and compare content of overlapping fields from the common format of the software model with the common format of the hardware model, and a positive outcome of the first and second comparisons represents that that the one or more network devices accurately created the hardware model from the global logical model. In some examples, the hardware model has a format that is different from the first format and the second format, the second format is one of the second and third formats, or is different from both of the second and third formats,

Also disclosed are systems, methods and CRM for event generation in network assurance of a network. The systems, methods and CRM can be configured to receive from a controller a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within each other through one or more network devices within the fabric and receive from one or more network devices within the fabric a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices and a hardware model of hardware configurations converted from the software model. The systems, methods and CRM can also be configured to validate accuracy of the received global logical model, the received software model and the received hardware model and generate one or more events based on the validating

In some examples, systems, methods and CRM can be configured to store prior configurations and corresponding effectiveness of the prior configurations, identify any configuration in the received global logical model, the received software model and/or the receiving hardware model that is the same or similar to a stored prior configuration with a corresponding adverse effectiveness, and report of potential flaws in the received global logical model, the received software model and/or the receiving hardware model in response to a positive result of the identifying.

In some examples, the one or more events include an informational event in response to no identified inconsistencies resulting from the validating. In other examples, the one or more events includes an error event in response to at least one identified inconsistency resulting from the validating. In some examples, the error event can have different levels of severity based on a severity of the at least one inconsistency. In some examples, in response to an error event, the system further comprising instructions, which when executed by the at least one processor causes the at least one processor to independently validate secondary content within the received global logical model, the received software model and/or the receiving hardware model, the secondary content being related to original content for which the at least one inconsistency was generated.

Also disclosed are systems, methods and CRM for performing a Layer 1 network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive from a controller, a global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric, the instructions including access policies for at least one interface and receive from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices. In some examples, the systems, methods and CRM can be configured to validate that at least Layer 1 of the access policies within the received global logical model are properly configured on the one network devices, identify within the received software model a reported state of a physical link and a software link of one or more ports of the one or more network devices, obtain an actual state of the physical link and the software link of the one or more ports of the one or more network devices, compare the reported state of the physical link and the software link with the obtained actual state of the physical link and the software link and generate one or more events based on the validation and/or the comparison.

In some examples, systems, methods and CRM can be configured to confirm the received global logical model, a switch profile and an interface profile are present, the switch profile and interface profile are properly linked, and that the interface profile is properly linked to a global profile.

In some examples, systems, methods and CRM can be configured to generate an error event in response to the determination that one or more of the access policies are not configured on the at least one interface.

In some examples, systems, methods and CRM can be configured to generate an error even in response to the comparison indicating that the reported state of the physical link is active and the actual state of the physical link is down, or the reported state of physical link is down and the actual state of the physical link is active.

In some examples, systems, methods and CRM can be configured to generate an error event in response to the comparison indicating that the reported state of the software link is active and the actual state of the physical switch is down, or the reported state of physical switch is down and the actual state of the physical switch is active. In some examples, systems, methods and CRM can be configured to poll the one or more network devices for the actual state of the physical link and the software link.

Also disclosed are systems, methods and CRM for performing a Layer 2 network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric and receive, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices. The systems, methods and CRM can be configured to create a local logical model in the first format, the local logical model being at least a portion of the received global logical model that is specific to operability of the one or more network devices, convert at least a portion of Layer 2 content of the created local logical model and at least a portion of Layer 2 content of the received software model into a common format and compare content of at least some Layer 2 overlapping fields from the common format of the created local logical model and the common format of the received software model. In some examples, a positive outcome of the comparison represents that the one or more network devices earlier at least partially accurately created the software model from the global logical model. The systems, methods and CRM can also be configured to validate that at least some Layer 2 content of the global logical model is properly configured.

In some examples, at least a portion of Layer 2 content subject to the conversion and the comparison includes VLAN information and interface information, to thereby at least partially check correct deployment of any bridge domains and/or endpoint groups (EPG). In some examples the least some of the Layer 2 content subject to the validation includes, at Layer 2, that access policies are configured properly, EPGs are configured properly, that multiple EPGs when present on the one of the network devices are not using the same virtual local area network (VLAN), there are no overlapping VLANs, no duplicate VLANs at the switch level on a same switch, and no duplicate VLANS on a port level on the same port of a same switch.

The systems, methods and CRM can also be configured to receive from the one of the one or more network devices within the fabric a hardware model in a third format of hardware configurations converted from the software model, convert at least a portion of Layer 2 content of the received software model and/or at least a portion of Layer 2 content of the hardware model into the common format. and compare content of at least some of Layer 2 overlapping fields from the common format of the received software model with the common format of the received hardware model. In some examples, a positive outcome of the comparison represents that the one or more network devices at least partially accurately converted Layer 2 of the software model into the hardware model. In some examples, at least a portion of the Layer 2 content subject to the conversions and the comparisons includes the VLAN for each EPG.

The systems, methods and CRM can also be configured receive a Distributed Virtual Switch (DVS) logical model from a DVS outside of the fabric, convert at least a portion of Layer 2 content of the received DVS logical model and/or at least a portion of Layer 2 content of the received global hardware model into a third common format and compare content of at least some of Layer 2 overlapping fields from the third common format of the received global logical model with the third common format of the received DVS logical model. In some examples, a positive outcome of the third comparing represents VLANs within the global logical model have been properly assigned across the network.

Also disclosed are systems, methods and CRM for performing a Layer 3 BD subnets properly deployed network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric, the global logical model including at least one virtual routing and forwarding instance (VRF) and receive, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices. The systems, methods and CRM can also be configured to convert, for each network device, the global model into a local logical model in the first format, the local logical model being at least a portion of the received global logical model that is specific to operability of the corresponding each network device, create a container for each VRF in the received global logical model, populate each of the created containers with the local logical model and the software model for each of the network devices associated with the VRF and confirm bridge domain (BD) subnets in the populated containers match. In some examples, the population includes a set union, such that the populated VRF container does not contain any duplicative BD subnets.

In some examples, the populated container includes a software model without a corresponding local logical model represents an improper extra item. In some examples, the populated container includes a local logical model without a corresponding software model represents an error in deployment of the global logical model.

The systems, methods and CRM can also be configured to subtract one of the software models from a corresponding local logical hardware model, subtract the corresponding local logical model from the one of the software models. In some examples, a mismatch between the subtractions represents a discrepancy. In some examples, an error event is generated in response to a mismatch between the subtractions. In some examples, an error event is generated in response to a mismatch in the bridge domain (BD) subnets in the populated container.

Also disclosed are systems, methods and CRM for performing a Layer 3 VRF container network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive a global logic model, a plurality of software models and a plurality of hardware models, the global logic model including virtual routing instance (VRF). The systems, methods and CRM can also be configured to create a plurality of local logical models from the global logical model, create, for the received VRF, a VRF container. populate the created VRF container with a subset of the received software models, the received hardware models, and/or the created local logical models, the subset being defined by one or more network devices in the fabric that are associated with the VRF of the received global logical model and identify within the populated VRF container one or more of the received software models, the received hardware models, and/or the created local logical models that correspond to one or more network devices in the fabric that is not associated with the VRF of the received global logical model. In some examples, a positive result of the identification represents a discrepancy in the global logical model.

In some examples, systems, methods and CRM can be configured to validate that the global logical model is consistent with the software models and/or the hardware models. In some examples, systems, methods and CRM can be configured to compare overlapping fields of content between one of the local logic models and one of the software models. In some examples, systems, methods and CRM can be configured to compare overlapping fields of content between one of the software models and one of the hardware models. In some examples, systems, methods and CRM can be configured to generate an error event in response to a positive result of the identification.

In some examples, the software models are based on the global logical model. In some examples, the hardware models are based on corresponding software models.

Also disclosed are systems, methods and CRM for performing a RIB-FIB network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to obtain a forwarding information base (FIB) and a routing information base (RIB) of the network device, convert the FIB and/or the RIB to a common format, remove from the RIB and FIB duplicates, determine whether a RIB entry in the RIB matches an entry in the FIB, identify, in response to a negative result of the determination, when the entry in the FIB is covered by another RIB entry. In some examples, an error event can be generated in response to a negative result of the identification.

In some examples, systems, methods and CRM can be configured to determine an IP address/mask and next hop of an entry in the FIB matches the RIB entry. In some examples, systems, methods and CRM can be configured to identify a FIB entry in the FIB that has a next hop that matches the unmatched RIB entry and an IP address/mask that covers the unmatched RIB entry. In some examples, systems, methods and CRM can be configured to identify a FIB entry in the FIB that has an alternative subnet prefix that completely covers the unmatched RIB entry.

In some examples, the FIB is obtained from a line controller of the network device and the RIB is extracted from SUP controller of the network device. In some examples, the network device is a leaf or spine in the fabric, and the system, method and CRM can be configured to obtain from the leaf or spine a software model containing the FIB and RIB. In some examples, systems, methods and CRM can be configured to determine is applied to every entry in the RIB.

Also disclosed are systems, methods and CRM for performing a Cross End Point Group network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive a global logic model, a plurality of software models and/or a plurality of hardware models, the global logic model including a virtual routing and forwarding instance (VRF), the VRF having under it at least one bridge domain (BD) and at least one associated EPG. The systems, methods and CRM can also be configured to create a plurality of local logical models from the received global logical model, create, for the VRF of the received global logical model, a VRF container, populate the created VRF container with a subset of the software models, the hardware models, and/or the local logical models, the subset being defined by leafs in the fabric on which the VRF is deployed, determine whether a security contract exists between any of the at least one EPG in the VRF container and an EPG not in the VRF container of the received global logical model and validate, in response to a positive result of the determination, that one or more subnets do not clash.

In some examples, each of the at least one BD includes at least one subnet. In some examples, each EPG of the at least one EPG includes at least one subnet.

The systems, methods and CRM can also be configured to determine a first set of subnets in a first BD associated with a first EPG where the contract exists, determine second set of subnets in a second BD associated with a second EPG where the contract exists and validate that the first set of subnets does not intersect with the second set of subnets. The systems, methods and CRM can also be configured to validate for each of the subnets, a next hop.

In some examples, an error event is generated in response to a clash between the one or more subnets. In some examples, an error event is generated in response to the first set of subnets intersecting with the second set of subnets.

Also disclosed are systems, methods and CRM for performing an overlapping subnet network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric and receive, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices. The systems, methods and CRM can also be configured to determine whether one or more overlapping bridge domain (BD) subnets in the received global logical model and the received software models, and in response to the determination an overlapping BD subnet of the one or more overlapping BD subnets, determine whether any of the one or more overlapping BD subnets satisfy an exception. In some examples, a negative result of either of the determinations at least partially represents that subnets have been properly deployed. In some examples, an error event is generated in response to overlap without an applicable exception.

The systems, methods and CRM can be configured to inspect IP addresses and masks of the software models and determine an overlap when two or more of the IP addresses and masks match. In some examples, the locating is performed in each VRF of each of the network devices. In some examples, an exception is when a BD subnet is within a learned route. In some examples, a positive result of either of the determinations at least partially represents that subnets have not been properly deployed. In some examples, an exception is when overlapping BD subnets are the same.

Also disclosed are systems, methods and CRM for performing an L3out network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric and receive, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices. The systems, methods and CRM can also be configured to create a local logical model in the first format, the local logical model being at least a portion of the received global logical model that is specific to operability of the one or more network devices, convert at least a portion of Layer 3 out (L3out) content of the created local logical model and/or at least a portion of L3out content of the received software model into a common format, and compare content of at least some L3out overlapping fields from the common format of the created local logical model and the common format of the received software model. In some examples, a positive outcome of the comparison at least partially represents that the internal subnet has been properly leaked outside of the fabric.

In some examples, at least some L3out overlapping fields subject to the comparison includes leaf, port and network to thereby at least partially validate that an L3out interface has been properly deployed. In some examples, at least some L3out overlapping fields subject to the comparison includes network devices to thereby at least partially validate that an L3out loopback has been properly deployed. In some examples, at least some L3out overlapping fields subject to the comparison includes leaf, and next hop to thereby at least partially validate that L3out static routes has been properly deployed. In some examples, at least some L3out overlapping fields subject to the comparison includes fields to thereby at least partially validate that endpoint groups has been properly deployed.

The systems, methods and CRM can be configured to validate each leaked internal subnet in the longest prefix match (LPM) table of the software model has a next hop that identifies which border leaf leaked the internal subnet, wherein a positive outcome of the validating at least partially represents that the internal subnet has been properly leaked outside of the fabric.

The systems, methods and CRM can be configured to validate that an LPM table of the border leaf has a next hop for the leaked internal subnet that identifies the network device, wherein a positive outcome of the validating at least partially represents that the internal subnet has been properly leaked outside of the fabric.

Also disclosed are systems, methods and CRM for performing a BD-L3out Association network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric, identify bridge domain (BD) subnets in the global logical model that are designated as public and validate, in response to a positive result of the identification, that the identified BDs are associated with an L3out. In some examples, a negative outcome of the identification or a positive result of the validation at least partially represents proper configuration a BD-Layer 3 out (L3out) relationship.

The systems, methods and CRM can also be configured to determine whether any of the identified BDs has a different endpoint group (EPG) from its corresponding L3out.

The systems, methods and CRM can also be configured to confirm, in response to a positive result of the determination, a presence of a contract between any of the identified BDs having a different endpoint group (EPG) from its corresponding L3out.

In some examples, a positive result of the confirmation at least partially represents proper configuration of the BD-L3out relationship. In some examples, an error event can be generated in response to a positive outcome of the identification. In some examples, an error event can be generated in response to a negative result of the validation. In some examples, an error event can be generated in response to a negative result of the confirmation.

Also disclosed are systems, methods and CRM for performing Learned routes network assurance check of proper deployment of a configuration in a fabric. The systems, methods and CRM can be configured to receive, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices. The systems, methods and CRM can also be configured to identify from the plurality of network devices a source leaf that imported an external subnet from an external device, the source leaf having an L3out under a virtual routing and forwarding instance (VRF), identify from the plurality of network devices a subgroup of leafs, the subgroup of leafs including the source leaf and other leafs having an L3out or BD under the VRF of the source leaf, confirm that the imported external subnet is consistent in the software model of one or more leafs of the group of leafs, determine, at the source leaf, the next hop of the imported network is the network device that requested the leak, and determine, at the other leafs, the next hop of the imported network is at least the source leaf. In some examples, a positive result of the determinations and the confirming at least partially represents proper propagation of the imported route. In some examples, a negative result of the determinations represents an improper propagation of the imported route. In some examples, a negative result of the confirmation represents an improper propagation of the imported route.

The systems, methods and CRM can also be configured to confirm that the imported external subnet is consistent in the software model of all leafs of the group of leafs further comprises instructions, which when executed by the at least one processor causes the at least one processor to confirm that the imported external subnet is consistent in the longest prefix match (LPM) table of the software model in all leafs of the group of leafs.

The systems, methods and CRM can also be configured to receive, from a controller, the global logical model containing instructions on how endpoints connected to a network fabric communicate within each other through one or more network devices within the fabric, and confirm that any imported routes in the global logical model are consistent with any imported routes in the received software models of border leafs of the plurality of leafs.

The systems, methods and CRM can also be configured to confirm that any imported routes in the global logical model are consistent with any imported routes in received software models of border leafs of the plurality of leafs comprises instructions, which when executed by the at least one processor, causes the at least one processor to confirm that LPM tables of the software models of border leafs include any imported routes found in an endpoint group (EPG) of Layer 3 out (L3out) of the global logical model.

The systems, methods and CRM can also be configured to confirm that any imported routes in the global logical model is consistent with any imported route received software models of border leafs of the plurality of leafs comprises instructions, which when executed by the at least one processor, causes the at least one processor to confirm that LPM tables of the software models of border leafs includes any imported routes found in an EPG of L3out of the global logical model and does not include other imported route unless imported from a different border leaf or a different L3out.

Description

The disclosed technology addresses the need in the art for accurate and efficient discovery of problems in a large and complex network or data center. The present technology involves system, methods, and computer-readable media for network assurance in layer 1, layer 2 and layer 3 of the networked environment. The present technology also involves system, methods, and computer-readable media for network assurance for internal-internal (e.g., inter-fabric) forwarding and internal-external (e.g., outside the fabric) forwarding in the networked environment. The network assurance can be performed using logical configurations, software configurations and/or hardware configurations. The present technology will be described in the following disclosure as follows. The discussion begins with an introductory discussion of network assurance and fault code aggregation across application-centric dimensions. An introductory discussion of network assurance and a description of example computing environments, as illustrated in FIGS. **1**A and **1**B, will then follow. The discussion continues with a description of systems and methods for network assurance, network modeling, and fault code aggregation across logical or application-centric dimensions, as shown in FIGS. **2**A-**2**D, **3**A-D, **4** and **5**A-B. The discussion continues with a description of systems and methods for routing and forwarding assurances and checks, as shown in FIG. **3**-**20**. The discussion concludes with a description of an example network device, as illustrated in FIG. **21**, and an example computing device, as illustrated in FIG. **22**, including example hardware components suitable for hosting software applications and performing computing operations.

The disclosure now turns to a discussion of network assurance and distributed fault code aggregation across logical or application-centric dimensions.

Network assurance is the guarantee or determination that the network is behaving as intended by the network operator and has been configured properly (e.g., the network is doing what it is intended to do). Intent can encompass various network operations, such as bridging, routing, security, service chaining, endpoints, compliance, QoS (Quality of Service), audits, etc. Intent can be embodied in one or more policies, settings, configurations, etc., defined for the network and individual network elements (e.g., switches, routers, applications, resources, etc.). However, often times, the configurations, policies, etc., defined by a network operator are incorrect or not accurately reflected in the actual behavior of the network. For example, a network operator specifies a configuration A for one or more types of traffic but later finds out that the network is actually applying configuration B to that traffic or otherwise processing that traffic in a manner that is inconsistent with configuration A. This can be a result of many different causes, such as hardware errors, software bugs, varying priorities, configuration conflicts, misconfiguration of one or more settings, improper rule rendering by devices, unexpected errors or events, software upgrades, configuration changes, failures, etc. As another example, a network operator implements configuration C but one or more other configurations result in the network behaving in a manner that is inconsistent with the intent reflected by the implementation of configuration C. For example, such a situation can result when configuration C conflicts with other configurations in the network.

The approaches herein can provide network assurance by modeling various aspects of the network and/or performing consistency checks as well as other network assurance checks. The approaches herein can also enable identification and visualization of hardware-level (e.g., network switch-level) errors along any software or application-centric dimension. Non-limiting example visualizations can include: 1) per-tenant error aggregation, 2) per-application profile error aggregation, 3) per-endpoint group pair aggregation, and 4) per-contract error aggregation. In this way, data center operators can quickly see hardware errors that impact particular tenants or other logical entities, across the entire network fabric, and even drill down by other dimensions, such as endpoint groups, to see only those relevant hardware errors. These visualizations speed root cause analysis, improving data center and application availability metrics. Given the scale of the network fabric, the aggregations to create these visualizations can be done in a distributed fashion.

In this context, a network assurance platform can run an assurance operator on each individual network device, such as a switch, and emit fault codes associated with the network device. A logical policy enricher can map the hardware IDs (e.g., scope, pcTag, etc.) to the logical policy entity that is defined in the software-defined network (SDN) fabric configuration, such as the application-centric infrastructure (ACI) fabric configuration. The mappings can yield enriched fault codes. The enriched fault codes can be sent to an aggregation layer for aggregation. For example, multiple nodes (e.g., HADOOP) can collect the enriched fault codes and emit them to an aggregation layer as (key, tag) pairs.

In some cases, the aggregation layer can scale horizontally by running the aggregator for each key as a separate reducer. Each key can represent a different dimension for aggregation. Non-limiting examples of dimensions include tenant, contract, application profile, endpoint group (EPG) pair, etc. This provides the operator of a large scale network fabric with an integrated view of the health of the network fabric for that particular dimension of aggregation. For example, this can provide the health of each tenant, contract, application profile, EPG pair, etc.

As previously noted, the fault code aggregation can implement logical models which can represent various aspects of a network. A model can include a mathematical or semantic model of the network, including, without limitation the network's policies, configurations, requirements, security, routing, topology, applications, hardware, filters, contracts, access control lists, EPGs, application profiles, tenants, etc. Models can be implemented to provide network assurance to ensure that the network is properly configured and the behavior of the network will be consistent (or is consistent) with the intended behavior reflected through specific policies, settings, definitions, etc., implemented by the network operator. Unlike traditional network monitoring which involves sending and analyzing data packets and observing network behavior, network assurance can be performed through modeling without necessarily ingesting any packet data or monitoring traffic or network behavior. This can result in foresight, insight, and hindsight: problems can be prevented before they occur, identified when they occur, and fixed immediately after they occur.

Properties of the network can be mathematically modeled to deterministically predict the behavior and condition of the network. A mathematical model can abstract the control, management, and data planes, and may use various techniques such as symbolic, formal verification, consistency, graph, behavioral, etc. The network can be determined to be healthy if the model(s) indicate proper behavior (e.g., no inconsistencies, conflicts, errors, etc.). The network can be determined to be functional, but not fully healthy, if the modeling indicates proper behavior but some inconsistencies. The network can be determined to be non-functional and not healthy if the modeling indicates improper behavior and errors. If inconsistencies or errors are detected by the modeling, a detailed analysis of the corresponding model(s) can allow one or more underlying or root problems to be identified with great accuracy.

The models can consume numerous types of data and/or events which model a large amount of behavioral aspects of the network. Such data and events can impact various aspects of the network, such as underlay services, overlay service, tenant connectivity, tenant security, tenant EP mobility, tenant policy, resources, etc.

Having described various aspects of network assurance and fault code aggregation across dimensions, the disclosure now turns to a discussion of example network environments for network assurance and fault code aggregation.

FIG. **1**A illustrates a diagram of an example Network Environment **100**, such as a data center. The Network Environment **100** can include a Fabric **120** which can represent the physical layer or infrastructure (e.g., underlay) of the Network Environment **100**. Fabric **120** can include Spines **102** (e.g., spine routers or switches) and Leafs **104** (e.g., leaf routers or switches) which can be interconnected for routing or switching traffic in the Fabric **120**. Spines **102** can interconnect Leafs **104** in the Fabric **120**, and Leafs **104** can connect the Fabric **120** to an overlay or logical portion of the Network Environment **100**, which can include application services, servers, virtual machines, containers, endpoints, etc. Thus, network connectivity in the Fabric **120** can flow from Spines **102** to Leafs **104**, and vice versa. The interconnections between Leafs **104** and Spines **102** can be redundant (e.g., multiple interconnections) to avoid a failure in routing. In some embodiments, Leafs **104** and Spines **102** can be fully connected, such that any given Leaf is connected to each of the Spines **102**, and any given Spine is connected to each of the Leafs **104**. Leafs **104** can be, for example, top-of-rack ("ToR") switches, aggregation switches, gateways, ingress and/or egress switches, provider edge devices, and/or any other type of routing or switching device.

Leafs **104** can be responsible for routing and/or bridging tenant or customer packets and applying network policies or rules. Network policies and rules can be driven by one or more Controllers **116**, and/or implemented or enforced by one or more devices, such as Leafs **104**. Leafs **104** can connect other elements to the Fabric **120**. For example, Leafs **104** can connect Servers **106**, Hypervisors **108**, Virtual Machines (VMs) **110**, Applications **112**, Network Device **114**, etc., with Fabric **120**. Such elements can reside in one or more logical or virtual layers or networks, such as an overlay network. In some cases, Leafs **104** can encapsulate and decapsulate packets to and from such elements (e.g., Servers **106**) in order to enable communications throughout Network Environment **100** and Fabric **120**. Leafs **104** can also provide any other devices, services, tenants, or workloads with access to Fabric **120**. In some cases, Servers **106** connected to Leafs **104** can similarly encapsulate and decapsulate packets to and from Leafs **104**. For example, Servers **106** can include one or more virtual switches or routers or tunnel endpoints for tunneling packets between an overlay or logical layer hosted by, or connected to, Servers **106** and an underlay layer represented by Fabric **120** and accessed via Leafs **104**.

Applications **112** can include software applications, services, containers, appliances, functions, service chains, etc. For example, Applications **112** can include a firewall, a database, a CDN server, an IDS/IPS, a deep packet inspection service, a message router, a virtual switch, etc. An application from Applications **112** can be distributed, chained, or hosted by multiple endpoints (e.g., Servers **106**, VMs **110**, etc.), or may run or execute entirely from a single endpoint.

VMs **110** can be virtual machines hosted by Hypervisors **108** or virtual machine managers running on Servers **106**. VMs **110** can include workloads running on a guest operating system on a respective server. Hypervisors **108** can provide a layer of software, firmware, and/or hardware that creates, manages, and/or runs the VMs **110**. Hypervisors **108** can allow VMs **110** to share hardware resources on Servers **106**, and the hardware resources on Servers **106** to appear as multiple, separate hardware platforms. Moreover, Hypervisors **108** on Servers **106** can host one or more VMs **110**.

In some cases, VMs **110** and/or Hypervisors **108** can be migrated to other Servers **106**. Servers **106** can similarly be migrated to other locations in Network Environment **100**. For example, a server connected to a specific leaf can be changed to connect to a different or additional leaf. Such configuration or deployment changes can involve modifications to settings, configurations and policies that are applied to the resources being migrated as well as other network components.

In some cases, one or more Servers **106**, Hypervisors **108**, and/or VMs **110** can represent or reside in a tenant or customer space. Tenant space can include workloads, services, applications, devices, networks, and/or resources that are associated with one or more clients or subscribers. Accordingly, traffic in Network Environment **100** can be routed based on specific tenant policies, spaces, agreements, configurations, etc. Moreover, addressing can vary between one or more tenants. In some configurations, tenant spaces can be divided into logical segments and/or networks and separated from logical segments and/or networks associated with other tenants. Addressing, policy, security and configuration information between tenants can be managed by Controllers **116**, Servers **106**, Leafs **104**, etc.

Configurations in Network Environment **100** can be implemented at a logical level, a hardware level (e.g., physical), and/or both. For example, configurations can be implemented at a logical and/or hardware level based on endpoint or resource attributes, such as endpoint types and/or application groups or profiles, through a software-defined network (SDN) framework (e.g., Application-Centric Infrastructure (ACI) or VMWARE NSX). To illustrate, one or more operators can define configurations at a logical level (e.g., application or software level) through Controllers **116**, which can implement or propagate such configurations through Network Environment **100**. In some examples, Controllers **116** can be Application Policy Infrastructure Controllers (APICs) in an ACI framework. In other examples, Controllers **116** can be one or more management components for associated with other SDN solutions, such as NSX Managers.

Such configurations can define rules, policies, priorities, protocols, attributes, objects, etc., for routing and/or classifying traffic in Network Environment **100**. For example, such configurations can define attributes and objects for classifying and processing traffic based on Endpoint Groups (EPGs), Security Groups (SGs), VM types, bridge domains (BDs), virtual routing and forwarding instances (VRFs), tenants, priorities, firewall rules, etc. Other example network objects and configurations are further described below. Traffic policies and rules can be enforced based on tags, attributes, or other characteristics of the traffic, such as protocols associated with the traffic, EPGs associated with the traffic, SGs associated with the traffic, network address information associated with the traffic, etc. Such policies and rules can be enforced by one or more elements in Network Environment **100**, such as Leafs **104**, Servers **106**, Hypervisors **108**, Controllers **116**, etc. As previously explained, Network Environment **100** can be configured according to one or more particular software-defined network (SDN) solutions, such as CISCO ACI or VMWARE NSX. These example SDN solutions are briefly described below.

ACI can provide an application-centric or policy-based solution through scalable distributed enforcement. ACI supports integration of physical and virtual environments under a declarative configuration model for networks, servers, services, security, requirements, etc. For example, the ACI framework implements EPGs, which can include a collection of endpoints or applications that share common configuration requirements, such as security, QoS, services, etc. Endpoints can be virtual/logical or physical devices, such as VMs, containers, hosts, or physical servers that are connected to Network Environment **100**. Endpoints can have one or more attributes such as a VM name, guest OS name, a security tag, application profile, etc. Application configurations can be applied between EPGs, instead of endpoints directly, in the form of contracts. Leafs **104** can classify incoming traffic into different EPGs. The classification can be based on, for example, a network segment identifier such as a VLAN ID, VXLAN Network Identifier (VNID), NVGRE Virtual Subnet Identifier (VSID), MAC address, IP address, etc.

In some cases, classification in the ACI infrastructure can be implemented by Application Virtual Switches (AVS), which can run on a host, such as a server or switch. For example, an AVS can classify traffic based on specified attributes, and tag packets of different attribute EPGs with different identifiers, such as network segment identifiers (e.g., VLAN ID). Finally, Leafs **104** can tie packets with their attribute EPGs based on their identifiers and enforce policies, which can be implemented and/or managed by one or more Controllers **116**. Leaf **104** can classify to which EPG the traffic from a host belongs and enforce policies accordingly.

Another example SDN solution is based on VMWARE NSX. With VMWARE NSX, hosts can run a distributed firewall (DFW) which can classify and process traffic. Consider a case where three types of VMs, namely, application, database and web VMs, are put into a single layer-**2** network segment. Traffic protection can be provided within the network segment based on the VM type. For example, HTTP traffic can be allowed among web VMs, and disallowed between a web VM and an application or database VM. To classify traffic and implement policies, VMWARE NSX can implement security groups, which can be used to group the specific VMs (e.g., web VMs, application VMs, database VMs). DFW rules can be configured to implement policies for the specific security groups. To illustrate, in the context of the previous example, DFW rules can be configured to block HTTP traffic between web, application, and database security groups.

Returning now to FIG. **1**A, Network Environment **100** can deploy different hosts via Leafs **104**, Servers **106**, Hypervisors **108**, VMs **110**, Applications **112**, and Controllers **116**, such as VMWARE ESXi hosts, WINDOWS HYPER-V hosts, bare metal physical hosts, etc. Network Environment **100** may interoperate with a variety of Hypervisors **108**, Servers **106** (e.g., physical and/or virtual servers), SDN orchestration platforms, etc. Network Environment **100** may implement a declarative model to allow its integration with application design and holistic network policy.

Controllers **116** can provide centralized access to fabric information, application configuration, resource configuration, application-level configuration modeling for a software-defined network (SDN) infrastructure, integration with management systems or servers, etc. Controllers **116** can form a control plane that interfaces with an application plane via northbound APIs and a data plane via southbound APIs.

As previously noted, Controllers **116** can define and manage application-level model(s) for configurations in Network Environment **100**. In some cases, application or device configurations can also be managed and/or defined by other components in the network. For example, a hypervisor or virtual appliance, such as a VM or container, can run a server or management tool to manage software and services in Network Environment **100**, including configurations and settings for virtual appliances.

As illustrated above, Network Environment **100** can include one or more different types of SDN solutions, hosts, etc. For the sake of clarity and explanation purposes, various examples in the disclosure will be described with reference to an ACI framework, and Controllers **116** may be interchangeably referenced as controllers, APICs, or APIC controllers. However, it should be noted that the technologies and concepts herein are not limited to ACI solutions and may be implemented in other architectures and scenarios, including other SDN solutions as well as other types of networks which may not deploy an SDN solution.

Further, as referenced herein, the term "hosts" can refer to Servers **106** (e.g., physical or logical), Hypervisors **108**, VMs **110**, containers (e.g., Applications **112**), etc., and can run or include any type of server or application solution. Non-limiting examples of "hosts" can include virtual switches or routers, such as distributed virtual switches (DVS), application virtual switches (AVS), vector packet processing (VPP) switches; VCENTER and NSX MANAGERS; bare metal physical hosts; HYPER-V hosts; VMs; DOCKER Containers; etc.

FIG. **1**B illustrates another example of Network Environment **100**. In this example, Network Environment **100** includes Endpoints **122** connected to Leafs **104** in Fabric **120**. Endpoints **122** can be physical and/or logical or virtual entities, such as servers, clients, VMs, hypervisors, software containers, applications, resources, network devices, workloads, etc. For example, an Endpoint **122** can be an object that represents a physical device (e.g., server, client, switch, etc.), an application (e.g., web application, database application, etc.), a logical or virtual resource (e.g., a virtual switch, a virtual service appliance, a virtualized network function (VNF), a VM, a service chain, etc.), a container running a software resource (e.g., an application, an appliance, a VNF, a service chain, etc.), storage, a workload or workload engine, etc. Endpoints **122** can have an address (e.g., an identity), a location (e.g., host, network segment, virtual routing and forwarding (VRF) instance, domain, etc.), one or more attributes (e.g., name, type, version, patch level, OS name, OS type, etc.), a tag (e.g., security tag), a profile, etc.

Endpoints **122** can be associated with respective Logical Groups **118**. Logical Groups **118** can be logical entities containing endpoints (physical and/or logical or virtual) grouped together according to one or more attributes, such as endpoint type (e.g., VM type, workload type, application type, etc.), one or more requirements (e.g., policy requirements, security requirements, QoS requirements, customer requirements, resource requirements, etc.), a resource name (e.g., VM name, application name, etc.), a profile, platform or operating system (OS) characteristics (e.g., OS type or name including guest and/or host OS, etc.), an associated network or tenant, one or more policies, a tag, etc. For example, a logical group can be an object representing a collection of endpoints grouped together. To illustrate, Logical Group **1** can contain client endpoints, Logical Group **2** can contain web server endpoints, Logical Group **3** can contain application server endpoints, Logical Group N can contain database server endpoints, etc. In some examples, Logical Groups **118** are EPGs in an ACI environment and/or other logical groups (e.g., SGs) in another SDN environment.

Traffic to and/or from Endpoints **122** can be classified, processed, managed, etc., based Logical Groups **118**. For example, Logical Groups **118** can be used to classify traffic to or from Endpoints **122**, apply policies to traffic to or from Endpoints **122**, define relationships between Endpoints **122**, define roles of Endpoints **122** (e.g., whether an endpoint consumes or provides a service, etc.), apply rules to traffic to or from Endpoints **122**, apply filters or access control lists (ACLs) to traffic to or from Endpoints **122**, define communication paths for traffic to or from Endpoints **122**, enforce requirements associated with Endpoints **122**, implement security and other configurations associated with Endpoints **122**, etc.

In an ACI environment, Logical Groups **118** can be EPGs used to define contracts in the ACI. Contracts can include rules specifying what and how communications between EPGs take place. For example, a contract can define what provides a service, what consumes a service, and what policy objects are related to that consumption relationship. A contract can include a policy that defines the communication path and all related elements of a communication or relationship between endpoints or EPGs. For example, a Web EPG can provide a service that a Client EPG consumes, and that consumption can be subject to a filter (ACL) and a service graph that includes one or more services, such as firewall inspection services and server load balancing.

FIG. **2**A illustrates a diagram of an example Management Information Model **200** for an SDN network, such as Network Environment **100**. The following discussion of Management Information Model **200** references various terms which shall also be used throughout the disclosure. Accordingly, for clarity, the disclosure shall first provide below a list of terminology, which will be followed by a more detailed discussion of Management Information Model **200**.

As used herein, an "Alias" can refer to a changeable name for a given object. Thus, even if the name of an object, once created, cannot be changed, the Alias can be a field that can be changed.

As used herein, the term "Aliasing" can refer to a rule (e.g., contracts, policies, configurations, etc.) that overlaps one or more other rules. For example, Contract **1** defined in a logical model of a network can be said to be aliasing Contract **2** defined in the logical model of the network if Contract **1** overlaps Contract **1**. In this example, by aliasing Contract **2**, Contract **1** may render Contract **2** redundant or inoperable. For example, if Contract **1** has a higher priority than Contract **2**, such aliasing can render Contract **2** redundant based on Contract l's overlapping and higher priority characteristics.

As used herein, the term "APIC" can refer to one or more controllers (e.g., Controllers **116**) in an ACI framework. The APIC can provide a unified point of automation and management, policy programming, application deployment, health monitoring for an ACI multitenant fabric. The APIC can be implemented as a single controller, a distributed controller, or a replicated, synchronized, and/or clustered controller.

As used herein, the term "BDD" can refer to a binary decision tree A binary decision tree can be a data structure representing functions, such as Boolean functions.

As used herein, the term "BD" can refer to a bridge domain. A bridge domain can be a set of logical ports that share the same flooding or broadcast characteristics. Like a virtual LAN (VLAN), bridge domains can span multiple devices. A bridge domain can be a L2 (Layer 2) construct.

As used herein, a "Consumer" can refer to an endpoint, resource, and/or EPG that consumes a service.

As used herein, a "Context" can refer to an L3 (Layer 3) address domain that allows multiple instances of a routing table to exist and work simultaneously. This increases functionality by allowing network paths to be segmented without using multiple devices. Non-limiting examples of a context or L3 address domain can include a Virtual Routing and Forwarding (VRF) instance, a private network, and so forth.

As used herein, the term "Contract" can refer to rules or configurations that specify what and how communications in a network are conducted (e.g., allowed, denied, filtered, processed, etc.). In an ACI network, contracts can specify how communications between endpoints and/or EPGs take place. In some examples, a contract can provide rules and configurations akin to an Access Control List (ACL).

As used herein, the term "Distinguished Name" (DN) can refer to a unique name that describes an object, such as an MO, and locates its place in Management Information Model **200**. In some cases, the DN can be (or equate to) a Fully Qualified Domain Name (FQDN).

As used herein, the term "Endpoint Group" (EPG) can refer to a logical entity or object associated with a collection or group of endpoints as previously described with reference to FIG. **1**B.

As used herein, the term "Filter" can refer to a parameter or configuration for allowing communications. For example, in a whitelist model where all communications are blocked by default, a communication must be given explicit permission to prevent such communication from being blocked. A filter can define permission(s) for one or more communications or packets. A filter can thus function similar to an ACL or Firewall rule. In some examples, a filter can be implemented in a packet (e.g., TCP/IP) header field, such as L3 protocol type, L4 (Layer 4) ports, and so on, which is used to allow inbound or outbound communications between endpoints or EPGs, for example.

As used herein, the term "L2 Out" can refer to a bridged connection. A bridged connection can connect two or more segments of the same network so that they can communicate. In an ACI framework, an L2 out can be a bridged (Layer 2) connection between an ACI fabric (e.g., Fabric **120**) and an outside Layer 2 network, such as a switch.

As used herein, the term "L3 Out" can refer to a routed connection. A routed Layer 3 connection uses a set of protocols that determine the path that data follows in order to travel across networks from its source to its destination. Routed connections can perform forwarding (e.g., IP forwarding) according to a protocol selected, such as BGP (border gateway protocol), OSPF (Open Shortest Path First), EIGRP (Enhanced Interior Gateway Routing Protocol), etc.

As used herein, the term "Managed Object" (MO) can refer to an abstract representation of objects that are managed in a network (e.g., Network Environment **100**). The objects can be concrete objects (e.g., a switch, server, adapter, etc.), or logical objects (e.g., an application profile, an EPG, a fault, etc.). The MOs can be network resources or elements that are managed in the network. For example, in an ACI environment, an MO can include an abstraction of an ACI fabric (e.g., Fabric **120**) resource.

As used herein, the term "Management Information Tree" (MIT) can refer to a hierarchical management information tree containing the MOs of a system. For example, in ACI, the MIT contains the MOs of the ACI fabric (e.g., Fabric **120**). The MIT can also be referred to as a Management Information Model (MIM), such as Management Information Model **200**.

As used herein, the term "Policy" can refer to one or more specifications for controlling some aspect of system or network behavior. For example, a policy can include a named entity that contains specifications for controlling some aspect of system behavior. To illustrate, a Layer 3 Outside Network Policy can contain the BGP protocol to enable BGP routing functions when connecting Fabric **120** to an outside Layer 3 network.

As used herein, the term "Profile" can refer to the configuration details associated with a policy. For example, a profile can include a named entity that contains the configuration details for implementing one or more instances of a policy. To illustrate, a switch node profile for a routing policy can contain the switch-specific configuration details to implement the BGP routing protocol.

As used herein, the term "Provider" refers to an object or entity providing a service. For example, a provider can be an EPG that provides a service.

As used herein, the term "Subject" refers to one or more parameters in a contract for defining communications. For example, in ACI, subjects in a contract can specify what information can be communicated and how. Subjects can function similar to ACLs.

As used herein, the term "Tenant" refers to a unit of isolation in a network. For example, a tenant can be a secure and exclusive virtual computing environment. In ACI, a tenant can be a unit of isolation from a policy perspective, but does not necessarily represent a private network. Indeed, ACI tenants can contain multiple private networks (e.g., VRFs). Tenants can represent a customer in a service provider setting, an organization or domain in an enterprise setting, or just a grouping of policies.

As used herein, the term "VRF" refers to a virtual routing and forwarding instance. The VRF can define a Layer 3 address domain that allows multiple instances of a routing table to exist and work simultaneously. This increases functionality by allowing network paths to be segmented without using multiple devices. Also known as a context or private network.

Having described various terms used herein, the disclosure now returns to a discussion of Management Information Model (MIM) **200** in FIG. **2**A. As previously noted, MIM **200** can be a hierarchical management information tree or MIT. Moreover, MIM **200** can be managed and processed by Controllers **116**, such as APICs in an ACI. Controllers **116** can enable the control of managed resources by presenting their manageable characteristics as object properties that can be inherited according to the location of the object within the hierarchical structure of the model.

The hierarchical structure of MIM **200** starts with Policy Universe **202** at the top (Root) and contains parent and child nodes **116**, **204**, **206**, **208**, **210**, **212**. Nodes **116**, **202**, **204**, **206**, **208**, **210**, **212** in the tree represent the managed objects (MOs) or groups of objects. Each object in the fabric (e.g., Fabric **120**) has a unique distinguished name (DN) that describes the object and locates its place in the tree. The Nodes **116**, **202**, **204**, **206**, **208**, **210**, **212** can include the various MOs, as described below, which contain policies that govern the operation of the system.

Controllers **116**

Controllers **116** (e.g., APIC controllers) can provide management, policy programming, application deployment, and health monitoring for Fabric **120**.

Node **204**

Node **204** includes a tenant container for policies that enable an operator to exercise domain-based access control. Non-limiting examples of tenants can include:

User tenants defined by the operator according to the needs of users. They contain policies that govern the operation of resources such as applications, databases, web servers, network-attached storage, virtual machines, and so on.

The common tenant is provided by the system but can be configured by the operator. It contains policies that govern the operation of resources accessible to all tenants, such as firewalls, load balancers, Layer 4 to Layer 7 services, intrusion detection appliances, and so on.

The infrastructure tenant is provided by the system but can be configured by the operator. It contains policies that govern the operation of infrastructure resources such as the fabric overlay (e.g., VXLAN). It also enables a fabric provider to selectively deploy resources to one or more user tenants. Infrastructure tenant polices can be configurable by the operator.

The management tenant is provided by the system but can be configured by the operator. It contains policies that govern the operation of fabric management functions used for in-band and out-of-band configuration of fabric nodes. The management tenant contains a private out-of-bound address space for the Controller/Fabric internal communications that is outside the fabric data path that provides access through the management port of the switches. The management tenant enables discovery and automation of communications with virtual machine controllers.

Node **206**

Node **206** can contain access policies that govern the operation of switch access ports that provide connectivity to resources such as storage, compute, Layer 2 and Layer 3 (bridged and routed) connectivity, virtual machine hypervisors, Layer 4 to Layer 7 devices, and so on. If a tenant requires interface configurations other than those provided in the default link, Cisco Discovery Protocol (CDP), Link Layer Discovery Protocol (LLDP), Link Aggregation Control Protocol (LACP), or Spanning Tree Protocol (STP), an operator can configure access policies to enable such configurations on the access ports of Leafs **104**.

Node **206** can contain fabric policies that govern the operation of the switch fabric ports, including such functions as Network Time Protocol (NTP) server synchronization, Intermediate System-to-Intermediate System Protocol (IS-IS), Border Gateway Protocol (BGP) route reflectors, Domain Name System (DNS) and so on. The fabric MO contains objects such as power supplies, fans, chassis, and so on.

Node **208**

Node **208** can contain VM domains that group VM controllers with similar networking policy requirements. VM controllers can share virtual space (e.g., VLAN or VXLAN space) and application EPGs. Controllers **116** communicate with the VM controller to publish network configurations such as port groups that are then applied to the virtual workloads.

Node **210**

Node **210** can contain Layer 4 to Layer 7 service integration life cycle automation framework that enables the system to dynamically respond when a service comes online or goes offline. Policies can provide service device package and inventory management functions.

Node **212**

Node **212** can contain access, authentication, and accounting (AAA) policies that govern user privileges, roles, and security domains of Fabric **120**.

The hierarchical policy model can fit well with an API, such as a REST API interface. When invoked, the API can read from or write to objects in the MIT. URLs can map directly into distinguished names that identify objects in the MIT. Data in the MIT can be described as a self-contained structured tree text document encoded in XML or JSON, for example.

FIG. **2**B illustrates an example object model **220** for a tenant portion of MIM **200**. As previously noted, a tenant is a logical container for application policies that enable an operator to exercise domain-based access control. A tenant thus represents a unit of isolation from a policy perspective, but it does not necessarily represent a private network. Tenants can represent a customer in a service provider setting, an organization or domain in an enterprise setting, or just a convenient grouping of policies. Moreover, tenants can be isolated from one another or can share resources.

Tenant portion **204**A of MIM **200** can include various entities, and the entities in Tenant Portion **204**A can inherit policies from parent entities. Non-limiting examples of entities in Tenant Portion **204**A can include Filters **240**, Contracts **236**, Outside Networks **222**, Bridge Domains **230**, VRF Instances **234**, and Application Profiles **224**.

Bridge Domains **230** can include Subnets **232**. Contracts **236** can include Subjects **238**. Application Profiles **224** can contain one or more EPGs **226**. Some applications can contain multiple components. For example, an e-commerce application could require a web server, a database server, data located in a storage area network, and access to outside resources that enable financial transactions. Application Profile **224** contains as many (or as few) EPGs as necessary that are logically related to providing the capabilities of an application.

EPG **226** can be organized in various ways, such as based on the application they provide, the function they provide (such as infrastructure), where they are in the structure of the data center (such as DMZ), or whatever organizing principle that a fabric or tenant operator chooses to use.

EPGs in the fabric can contain various types of EPGs, such as application EPGs, Layer 2 external outside network instance EPGs, Layer 3 external outside network instance EPGs, management EPGs for out-of-band or in-band access, etc. EPGs **226** can also contain Attributes **228**, such as encapsulation-based EPGs, IP-based EPGs, or MAC-based EPGs.

As previously mentioned, EPGs can contain endpoints (e.g., EPs **122**) that have common characteristics or attributes, such as common policy requirements (e.g., security, virtual machine mobility (VMM), QoS, or Layer 4 to Layer 7 services). Rather than configure and manage endpoints individually, they can be placed in an EPG and managed as a group.

Policies apply to EPGs, including the endpoints they contain. An EPG can be statically configured by an operator in Controllers **116**, or dynamically configured by an automated system such as VCENTER or OPENSTACK.

To activate tenant policies in Tenant Portion **204**A, fabric access policies should be configured and associated with tenant policies. Access policies enable an operator to configure other network configurations, such as port channels and virtual port channels, protocols such as LLDP, CDP, or LACP, and features such as monitoring or diagnostics.

FIG. **2**C illustrates an example Association **260** of tenant entities and access entities in MIM **200**. Policy Universe **202** contains Tenant Portion **204**A and Access Portion **206**A. Thus, Tenant Portion **204**A and Access Portion **206**A are associated through Policy Universe **202**.

Access Portion **206**A can contain fabric and infrastructure access policies. Typically, in a policy model, EPGs are coupled with VLANs. For traffic to flow, an EPG is deployed on a leaf port with a VLAN in a physical, VMM, L2 out, L3 out, or Fiber Channel domain, for example.

Access Portion **206**A thus contains Domain Profile **236** which can define a physical, VMM, L2 out, L3 out, or Fiber Channel domain, for example, to be associated to the EPGs. Domain Profile **236** contains VLAN Instance Profile **238** (e.g., VLAN pool) and Attachable Access Entity Profile (AEP) **240**, which are associated directly with application EPGs. The AEP **240** deploys the associated application EPGs to the ports to which it is attached, and automates the task of assigning VLANs. While a large data center can have thousands of active VMs provisioned on hundreds of VLANs, Fabric **120** can automatically assign VLAN IDs from VLAN pools. This saves time compared with trunking down VLANs in a traditional data center.

FIG. **2**D illustrates a schematic diagram of example models for a network, such as Network Environment **100**. The models can be generated based on specific configurations and/or network state parameters associated with various objects, policies, properties, and elements defined in MIM **200**. The models can be implemented for network analysis and assurance, and may provide a depiction of the network at various stages of implementation and levels of the network.

As illustrated, the models can include L_Model **270**A (Logical Model), LR_Model **270**B (Logical Rendered Model or Logical Runtime Model), Li_Model **272** (Logical Model for i), Ci_Model **274** (Concrete model for i), and/or Hi_Model **276** (Hardware model or TCAM Model for i).

L_Model **270**A is the logical representation of various elements in MIM **200** as configured in a network (e.g., Network Environment **100**), such as objects, object properties, object relationships, and other elements in MIM **200** as configured in a network. L_Model **270**A can be generated by Controllers **116** based on configurations entered in Controllers **116** for the network, and thus represents the logical configuration of the network at Controllers **116**. This is the declaration of the “end-state” expression that is desired when the elements of the network entities (e.g., applications, tenants, etc.) are connected and Fabric **120** is provisioned by Controllers **116**. Because L_Model **270**A represents the configurations entered in Controllers **116**, including the objects and relationships in MIM **200**, it can also reflect the “intent” of the operator: how the operator wants the network and network elements to behave.

L_Model **270**A can be a fabric or network-wide logical model. For example, L_Model **270**A can account configurations and objects from each of Controllers **116**. As previously explained, Network Environment **100** can include multiple Controllers **116**. In some cases, two or more Controllers **116** may include different configurations or logical models for the network. In such cases, L_Model **270**A can obtain any of the configurations or logical models from Controllers **116** and generate a fabric or network wide logical model based on the configurations and logical models from all Controllers **116**. L_Model **270**A can thus incorporate configurations or logical models between Controllers **116** to provide a comprehensive logical model. L_Model **270**A can also address or account for any dependencies, redundancies, conflicts, etc., that may result from the configurations or logical models at the different Controllers **116**.

L_Model **270**A is thus the first/highest level model. L_Model **270**A is created by the Controllers **116** based on input from the operator. The content within L_Model **270**A is thus the specific instructions on how various Leafs **104** and the Spines **102** within the Fabric **120** are to communicate with Endpoints **122**. In some examples, any particular L_Model **270**A can be “global” in that it can be generated at a central point to include instructions for all of the Leafs **104** and the Spines **102**, or only some of them (in theory it could be as small as one Leaf **104** or Spine **120**, although this would be unusual). The format is based on whatever the GUI interface and/or the Rest API allows the user to input the content. Multiple L_Model **270**A configurations may be present.

The format of L_Model **270**A is in the program format of the user to generate the instructions, and not useable as is by Controller **116**. Controller **116** converts L_Model **270**A as a first level into LR_Model **270**B as a second level, for which LR_Model **270**B is a logical representation that contains the content of L-Model **270**A in a format that is readable on Controller **116** and transmittable to Leafs **104** and Spines **102**. As this is a format change, the information content of L_Model **270**A and LR_Model **270**B can be the same, although the application is not so limited and the content can be omitted or added to create LR_Model **270**B.

LR_Model **270**B is thus the abstract model expression that Controllers **116** (e.g., APICs in ACI) resolve from L_Model **270**A. LR_Model **270**B can provide the configuration components that would be delivered to the physical infrastructure (e.g., Fabric **120**) to execute one or more policies. For example, LR_Model **270**B can be delivered to Leafs **104** in Fabric **120** to configure Leafs **104** for communication with attached Endpoints **122**. LR_Model **270**B can also incorporate state information to capture a runtime state of the network (e.g., Fabric **120**).

In some cases, LR_Model **270**B can provide a representation of L_Model **270**A that is normalized according to a specific format or expression that can be propagated to, and/or understood by, the physical infrastructure of Fabric **120** (e.g., Leafs **104**, Spines **102**, etc.). For example, LR_Model **270**B can associate the elements in L_Model **270**A with specific identifiers or tags that can be interpreted and/or compiled by the switches in Fabric **120**, such as hardware plane identifiers used as classifiers.

Controller **116** transmits L_Model **270**A and/or LR_Model **270**B (referred to herein individually and collectively as “L_Model **270**A/B”) to relevant Leafs **104** and Spines **102** in the Fabric **120**. Relevance may be defined by Controller **116** to be all of the Leafs **104** and Spines **102**, or some subset thereof. By way of non-limiting example, Fabric **120** of FIG. **1**B includes Leaf **1**, Leaf **2** and Leaf N. An L_Model **270**A/B at Controller **116** may only include content for Leaf **1** and Leaf N, but not Leaf **2**. Controller **116** could thus transmit the L_Model **270**A/B to all of Leafsl, **2** and N, or only to relevant Leafs **1** and N.

Controller **116** and/or or each particular Leaf **104** and Spine **102** that receives L_Model **270**A/B then extracts/isolates content from the received model to form a local subset of content that is specific to that particular Leaf or Spine. This extracted/isolated content defines the third level Li_Model **272**, which is a switch-level or switch-specific logical model; Li_Model **272** is thus “local” in that is specific to that switch (although it may include content on the switch's relationship with other switches). Li_Model **272** is thus a switch-level or switch-specific model obtained from L_Model **270**A and/or LR_Model **270**B. Li_Model **272** can project L_Model **270**A and/or LR_Model **270**B on a specific switch or device i, and thus can convey how L_Model **270**A and/or LR_Model **270**B should appear or be implemented at the specific switch or device i.

For example, Li_Model **272** can project L_Model **270**A and/or LR_Model **270**B pertaining to a specific switch i to capture a switch-level representation of L_Model **270**A and/or LR_Model **270**B at switch i. To illustrate, Li_Model **272** L1 can represent L_Model **270**A and/or LR_Model **270**B projected to, or implemented at, Leaf **1** (**104**). Thus, Li_Model **272** can be generated from L_Model **270**A and/or LR_Model **270**B for individual devices (e.g., Leafs **104**, Spines **102**, etc.) on Fabric **120**. By way of non-limiting example, if the L_Model **270**A/B includes instructions for Leaf **1** and Leaf N, then Leaf **1** will extract/isolate the content relevant to the operation of Leaf **1** to define local L1_Model **272**, and Leaf N will extract/isolate the content relevant to the operation of Leaf N to define local LN_Model **272**. Since the L_Model **270**A/B did not include instructions for Leaf **2**, then even if Leaf **2** received the L_Model **270**A/B it would not create its own local L2_Model, although the application is not so limited. To the extent that the local Li_Model **272** is a subset of L_Model **270**A/B, then this represents a change of content. To the extent that local Li_Model **272** is an extraction/isolation of the content from LR_Model **270**B, there is generally no change in format, although the application is not so limited.

In some cases, Li_Model **272** can be represented using JSON (JavaScript Object Notation). For example, Li_Model **272** can include JSON objects, such as Rules, Filters, Entries, and Scopes.

Each Li_Model **272** may not be in a format executable by the particular Leaf **104** or Spine **102** on which it was created (e.g., it may not be executable on the local operating system of that Leaf or Spine). Each Leaf **104** and Spine **102** can thus locally create the fourth level by converting the format of the Li_Model **272** into a format that the operating system of that particular Leaf **104** or Spine **102** can execute. This results in Ci_Model **274**, referred to herein as a software model or a concrete model. Thus, by way of non-limiting example, where Leaf N created a local LN_Model **272** from L_Model **270**A/B, Leaf N will in turn create a local CN_Model **274** from LN_Model **272**.

Ci_Model **274** is thus the actual in-state configuration at the individual fabric member i (e.g., switch i). In other words, Ci_Model **274** is a switch-level or switch-specific model that is based on Li_Model **272**. For example, Controllers **116** can deliver Li_Model **272** to Leaf **1** (**104**). Leaf **1** (**104**) can take Li_Model **272**, which can be specific to Leaf **1** (**104**), and render the policies in Li_Model **272** into a concrete model, Ci_Model **274**, that runs on Leaf **1** (**104**). Leaf **1** (**104**) can render Li_Model **272** via the OS on Leaf **1** (**104**), for example. Thus, Ci_Model **274** can be analogous to compiled software, as it is the form of Li_Model **272** that the switch OS at Leaf **1** (**104**) can execute.

The creation of local Li_Model **274** from Ci_Model **274** represents at least a change in format. The content of the Li_Model **272** may be the same Ci_Model **274** such that there is no content change, although the application is not so limited and the content may only overlap. By way of example, not all of the content from Li_Model **272** may be included in the corresponding Ci_Model **274**. Similarly, the particular Leaf **104** or Spine **102** can add content to Ci_Model **274** that was not present in Li_Model Model **272**.

In some cases, Li_Model **272** and Ci_Model **274** can have a same or similar format. For example, Li_Model **272** and Ci_Model **274** can be based on JSON objects. Having the same or similar format can facilitate objects in Li_Model **272** and Ci_Model **274** to be compared for equivalence or congruence. Such equivalence or congruence checks can be used for network analysis and assurance, as further described herein.

Each Leaf **104** and Spine **102** that creates a Ci_Model **274** as a fourth level will in turn create a fifth level as a local hardware model Hi_Model **276**. Hi_Model **276** represents the actual hardware configurations from Ci_Model **274** that are extracted and stored in the local memory. The conversion of Ci_Model **274** into Hi Model **276** represents both a format and content change. Similarly, the particular Leaf **104** or Spine **102** can add content to Hi_Model **276** that was not present in Ci_Model Model **274**.

Hi_Model **276** is thus also a switch-level or switch-specific model for switch i, but is based on Ci_Model **274** for switch i. Hi_Model **276** is the actual configuration (e.g., rules) stored or rendered on the hardware or memory (e.g., TCAM memory) at the individual fabric member i (e.g., switch i). For example, Hi_Model **276** can represent the configurations (e.g., rules) which Leaf **1** (**104**) stores or renders on the hardware (e.g., TCAM memory) of Leaf **1** (**104**) based on Ci_Model **274** at Leaf **1** (**104**). The switch OS at Leaf **1** (**104**) can render or execute Ci_Model **274**, and Leaf **1** (**104**) can store or render the configurations from Ci_Model **274** in storage, such as the memory or TCAM at Leaf **1** (**104**). The configurations from Hi_Model **276** stored or rendered by Leaf **1** (**104**) represent the configurations that will be implemented by Leaf **1** (**104**) when processing traffic.

While Models **272**, **274**, **276** are shown as device-specific models, similar models can be generated or aggregated for a collection of fabric members (e.g., Leafs **104** and/or Spines **102**) in Fabric **120**. When combined, device-specific models, such as Model **272**, Model **274**, and/or Model **276**, can provide a representation of Fabric **120** that extends beyond a particular device. For example, in some cases, Li_Model **272**, Ci_Model **274**, and/or Hi_Model **276** associated with some or all individual fabric members (e.g., Leafs **104** and Spines **102**) can be combined or aggregated to generate one or more aggregated models based on the individual fabric members.

As referenced herein, the terms H Model, T Model, and TCAM Model can be used interchangeably to refer to a hardware model, such as Hi_Model **276**. For example, Ti Model, Hi Model and TCAMi Model may be used interchangeably to refer to Hi_Model **276**.

Models **270**A, **270**B, **272**, **274**, **276** can provide representations of various aspects of the network or various configuration stages for MIM **200**. For example, one or more of Models **270**A, **270**B, **272**, **274**, **276** can be used to generate Underlay Model **278** representing one or more aspects of Fabric **120** (e.g., underlay topology, routing, etc.), Overlay Model **280** representing one or more aspects of the overlay or logical segment(s) of Network Environment **100** (e.g., COOP, MPBGP, tenants, VRFs, VLANs, VXLANs, virtual applications, VMs, hypervisors, virtual switching, etc.), Tenant Model **282** representing one or more aspects of Tenant portion **204**A in MIM **200** (e.g., security, forwarding, service chaining, QoS, VRFs, BDs, Contracts, Filters, EPGs, subnets, etc.), Resources Model **284** representing one or more resources in Network Environment **100** (e.g., storage, computing, VMs, port channels, physical elements, etc.), etc.

In general, L_Model **270**A can be the high-level expression of what exists in the LR_Model **270**B, which should be present on the concrete devices as Ci_Model **274** and Hi_Model **276** expression. If there is any gap between the models, there may be inconsistent configurations or problems.

FIG. **3**A illustrates a diagram of an example Assurance Appliance **300** for network assurance. In this example, Assurance Appliance **300** can include k VMs **110** operating in cluster mode. VMs are used in this example for explanation purposes. However, it should be understood that other configurations are also contemplated herein, such as use of containers, bare metal devices, Endpoints **122**, or any other physical or logical systems. Moreover, while FIG. **3**A illustrates a cluster mode configuration, other configurations are also contemplated herein, such as a single mode configuration (e.g., single VM, container, or server) or a service chain for example.

Assurance Appliance **300** can run on one or more Servers **106**, VMs **110**, Hypervisors **108**, EPs **122**, Leafs **104**, Controllers **116**, or any other system or resource. For example, Assurance Appliance **300** can be a logical service or application running on one or more VMs **110** in Network Environment **100**.

The Assurance Appliance **300** can include Data Framework **308**, which can be based on, for example, APACHE APEX and HADOOP. In some cases, assurance checks can be written as individual operators that reside in Data Framework **308**. This enables a natively horizontal scale-out architecture that can scale to arbitrary number of switches in Fabric **120** (e.g., ACI fabric).

Assurance Appliance **300** can poll Fabric **120** at a configurable periodicity (e.g., an epoch). The analysis workflow can be setup as a DAG (Directed Acyclic Graph) of Operators **310**, where data flows from one operator to another and eventually results are generated and persisted to Database **302** for each interval (e.g., each epoch).

The north-tier implements API Server (e.g., APACHE Tomcat and Spring framework) **304** and Web Server **306**. A graphical user interface (GUI) interacts via the APIs exposed to the customer. These APIs can also be used by the customer to collect data from Assurance Appliance **300** for further integration into other tools.

Operators **310** in Data Framework **308** (e.g., APEX/Hadoop) can together support assurance operations. Below are non-limiting examples of assurance operations that can be performed by Assurance Appliance **300** via Operators **310**.

Security Policy Adherence

Assurance Appliance **300** can check to make sure the configurations or specification from L_Model **270**A, which may reflect the user's intent for the network, including for example the security policies and customer-configured contracts, are correctly implemented and/or rendered in Li_Model **272**, Ci_Model **274**, and Hi_Model **276**, and thus properly implemented and rendered by the fabric members (e.g., Leafs **104**), and report any errors, contract violations, or irregularities found.

Static Policy Analysis

Assurance Appliance **300** can check for issues in the specification of the user's intent or intents (e.g., identify contradictory or conflicting policies in L_Model **270**A).

TCAM Utilization

TCAM is a scarce resource in the fabric (e.g., Fabric **120**). However, Assurance Appliance **300** can analyze the TCAM utilization by the network data (e.g., Longest Prefix Match (LPM) tables, routing tables, VLAN tables, BGP updates, etc.), Contracts, Logical Groups **118** (e.g., EPGs), Tenants, Spines **102**, Leafs **104**, and other dimensions in Network Environment **100** and/or objects in MIM **200**, to provide a network operator or user visibility into the utilization of this scarce resource. This can greatly help for planning and other optimization purposes.

Endpoint Checks

Assurance Appliance **300** can validate that the fabric (e.g. fabric **120**) has no inconsistencies in the Endpoint information registered (e.g., two leafs announcing the same endpoint, duplicate subnets, etc.), among other such checks.

Tenant Routing Checks

Assurance Appliance **300** can validate that BDs, VRFs, subnets (both internal and external), VLANs, contracts, filters, applications, EPGs, etc., are correctly programmed.

Infrastructure Routing

Assurance Appliance **300** can validate that infrastructure routing (e.g., IS-IS protocol) has no convergence issues leading to black holes, loops, flaps, and other problems.

MP-BGP Route Reflection Checks

The network fabric (e.g., Fabric **120**) can interface with other external networks and provide connectivity to them via one or more protocols, such as Border Gateway Protocol (BGP), Open Shortest Path First (OSPF), etc. The learned routes are advertised within the network fabric via, for example, MP-BGP. These checks can ensure that a route reflection service via, for example, MP-BGP (e.g., from Border Leaf) does not have health issues.

Logical Lint and Real-time Change Analysis

Assurance Appliance **300** can validate rules in the specification of the network (e.g., L_Model **270**A) are complete and do not have inconsistencies or other problems. MOs in the MIM **200** can be checked by Assurance Appliance **300** through syntactic and semantic checks performed on L_Model **270**A and/or the associated configurations of the MOs in MIM **200**. Assurance Appliance **300** can also verify that unnecessary, stale, unused or redundant configurations, such as contracts, are removed.

FIG. **3**B illustrates an architectural diagram of an example system **350** for network assurance, such as Assurance Appliance **300**. In some cases, system **350** can correspond to the DAG of Operators **310** previously discussed with respect to FIG. **3**A

In this example, Topology Explorer **312** communicates with Controllers **116** (e.g., APIC controllers) in order to discover or otherwise construct a comprehensive topological view of Fabric **120** (e.g., Spines **102**, Leafs **104**, Controllers **116**, Endpoints **122**, and any other components as well as their interconnections). While various architectural components are represented in a singular, boxed fashion, it is understood that a given architectural component, such as Topology Explorer **312**, can correspond to one or more individual Operators **310** and may include one or more nodes or endpoints, such as one or more servers, VMs, containers, applications, service functions (e.g., functions in a service chain or virtualized network function), etc.

Topology Explorer **312** is configured to discover nodes in Fabric **120**, such as Controllers **116**, Leafs **104**, Spines **102**, etc. Topology Explorer **312** can additionally detect a majority election performed amongst Controllers **116**, and determine whether a quorum exists amongst Controllers **116**. If no quorum or majority exists, Topology Explorer **312** can trigger an event and alert a user that a configuration or other error exists amongst Controllers **116** that is preventing a quorum or majority from being reached. Topology Explorer **312** can detect Leafs **104** and Spines **102** that are part of Fabric **120** and publish their corresponding out-of-band management network addresses (e.g., IP addresses) to downstream services. This can be part of the topological view that is published to the downstream services at the conclusion of Topology Explorer's **312** discovery epoch (e.g., 5 minutes, or some other specified interval).

In some examples, Topology Explorer **312** can receive as input a list of Controllers **116** (e.g., APIC controllers) that are associated with the network/fabric (e.g., Fabric **120**). Topology Explorer **312** can also receive corresponding credentials to login to each controller. Topology Explorer **312** can retrieve information from each controller using, for example, REST calls. Topology Explorer **312** can obtain from each controller a list of nodes (e.g., Leafs **104** and Spines **102**), and their associated properties, that the controller is aware of. Topology Explorer **312** can obtain node information from Controllers **116** including, without limitation, an IP address, a node identifier, a node name, a node domain, a node URI, a node_dm, a node role, a node version, etc.

Topology Explorer **312** can also determine if Controllers **116** are in quorum, or are sufficiently communicatively coupled amongst themselves. For example, if there are n controllers, a quorum condition might be met when (n/2+1) controllers are aware of each other and/or are communicatively coupled. Topology Explorer **312** can make the determination of a quorum (or identify any failed nodes or controllers) by parsing the data returned from the controllers, and identifying communicative couplings between their constituent nodes. Topology Explorer **312** can identify the type of each node in the network, e.g. spine, leaf, APIC, etc., and include this information in the topology information generated (e.g., topology map or model).

If no quorum is present, Topology Explorer **312** can trigger an event and alert a user that reconfiguration or suitable attention is required. If a quorum is present, Topology Explorer **312** can compile the network topology information into a JSON object and pass it downstream to other operators or services, such as Unified Collector **314**.

Unified Collector **314** can receive the topological view or model from Topology Explorer **312** and use the topology information to collect information for network assurance from Fabric **120**. Unified Collector **314** can poll nodes (e.g., Controllers **116**, Leafs **104**, Spines **102**, etc.) in Fabric **120** to collect information from the nodes.

Unified Collector **314** can include one or more collectors (e.g., collector devices, operators, applications, VMs, etc.) configured to collect information from Topology Explorer **312** and/or nodes in Fabric **120**. For example, Unified Collector **314** can include a cluster of collectors, and each of the collectors can be assigned to a subset of nodes within the topological model and/or Fabric **120** in order to collect information from their assigned subset of nodes. For performance, Unified Collector **314** can run in a parallel, multi-threaded fashion.

Unified Collector **314** can perform load balancing across individual collectors in order to streamline the efficiency of the overall collection process. Load balancing can be optimized by managing the distribution of subsets of nodes to collectors, for example by randomly hashing nodes to collectors.

In some cases, Assurance Appliance **300** can run multiple instances of Unified Collector **314**. This can also allow Assurance Appliance **300** to distribute the task of collecting data for each node in the topology (e.g., Fabric **120** including Spines **102**, Leafs **104**, Controllers **116**, etc.) via sharding and/or load balancing, and map collection tasks and/or nodes to a particular instance of Unified Collector **314** with data collection across nodes being performed in parallel by various instances of Unified Collector **314**. Within a given node, commands and data collection can be executed serially. Assurance Appliance **300** can control the number of threads used by each instance of Unified Collector **314** to poll data from Fabric **120**.

Unified Collector **314** can collect models (e.g., L_Model **270**A and/or LR_Model **270**B) from Controllers **116**, switch software configurations and models (e.g., Ci_Model **274**) from nodes (e.g., Leafs **104** and/or Spines **102**) in Fabric **120**, hardware configurations and models (e.g., Hi_Model **276**) from nodes (e.g., Leafs **104** and/or Spines **102**) in Fabric **120**, etc. Unified Collector **314** can collect Ci Model **274** and Hi Model **276** from individual nodes or fabric members, such as Leafs **104** and Spines **102**, and L_Model **270**A and/or LR_Model **270**B from one or more controllers (e.g., Controllers **116**) in Network Environment **100**.

Unified Collector **314** can poll the devices that Topology Explorer **312** discovers in order to collect data from Fabric **120** (e.g., from the constituent members of the fabric) .Unified Collector **314** can collect the data using interfaces exposed by Controllers **116** and/or switch software (e.g., switch OS), including, for example, a Representation State Transfer (REST) Interface and a Secure Shell (SSH) Interface.

In some cases, Unified Collector **314** collects L_Model **270**A, LR_Model **270**B, and/or Ci_Model **274** via a REST API, and the hardware information (e.g., configurations, tables, fabric card information, rules, routes, etc.) via SSH using utilities provided by the switch software, such as virtual shell (VSH or VSHELL) for accessing the switch command-line interface (CLI) or VSH_LC shell for accessing runtime state of the line card.

Unified Collector **314** can poll other information from Controllers **116**, including, without limitation: topology information, tenant forwarding/routing information, tenant security policies, contracts, interface policies, physical domain or VMM domain information, OOB (out-of-band) management IP's of nodes in the fabric, etc.

Unified Collector **314** can also poll information from nodes (e.g., Leafs **104** and Spines **102**) in Fabric **120**, including without limitation: Ci_Models **274** for VLANs, BDs, and security policies; Link Layer Discovery Protocol (LLDP) connectivity information of nodes (e.g., Leafs **104** and/or Spines **102**); endpoint information from EPM/COOP; fabric card information from Spines **102**; routing information base (RIB) tables from nodes in Fabric **120**; forwarding information base (FIB) tables from nodes in Fabric **120**; security group hardware tables (e.g., TCAM tables) from nodes in Fabric **120**; etc.

In some cases, Unified Collector **314** can obtain runtime state from the network and incorporate runtime state information into L_Model **270**A and/or LR_Model **270**B. Unified Collector **314** can also obtain multiple logical models from Controllers **116** and generate a comprehensive or network-wide logical model (e.g., L_Model **270**A and/or LR_Model **270**B) based on the logical models. Unified Collector **314** can compare logical models from Controllers **116**, resolve dependencies, remove redundancies, etc., and generate a single L Model **270**A and/or LR Model **270**B for the entire network or fabric.

Unified Collector **314** can collect the entire network state across Controllers **116** and fabric nodes or members (e.g., Leafs **104** and/or Spines **102**). For example, Unified Collector **314** can use a REST interface and an SSH interface to collect the network state. This information collected by Unified Collector **314** can include data relating to the link layer, VLANs, BDs, VRFs, security policies, etc. The state information can be represented in LR_Model **270**B, as previously mentioned. Unified Collector **314** can then publish the collected information and models to any downstream operators that are interested in or require such information. Unified Collector **314** can publish information as it is received, such that data is streamed to the downstream operators.

Data collected by Unified Collector **314** can be compressed and sent to downstream services. In some examples, Unified Collector **314** can collect data in an online fashion or real-time fashion, and send the data downstream, as it is collected, for further analysis. In some examples, Unified Collector **314** can collect data in an offline fashion, and compile the data for later analysis or transmission.

Assurance Appliance **300** can contact Controllers **116**, Spines **102**, Leafs **104**, and other nodes to collect various types of data. In some scenarios, Assurance Appliance **300** may experience a failure (e.g., connectivity problem, hardware or software error, etc.) that prevents it from being able to collect data for a period of time. Assurance Appliance **300** can handle such failures seamlessly, and generate events based on such failures.

Switch Logical Policy Generator **316** can receive L_Model **270**A and/or LR_Model **270**B from Unified Collector **314** and calculate Li_Model **272** for each network device i (e.g., switch i) in Fabric **120**. For example, Switch Logical Policy Generator **316** can receive L_Model **270**A and/or LR_Model **270**B and generate Li_Model **272** by projecting a logical model for each individual node i (e.g., Spines **102** and/or Leafs **104**) in Fabric **120**. Switch Logical Policy Generator **316** can generate Li_Model **272** for each switch in Fabric **120**, thus creating a switch logical model based on L_Model **270**A and/or LR_Model **270**B for each switch.

Each Li_Model **272** can represent L_Model **270**A and/or LR_Model **270**B as projected or applied at the respective network device i (e.g., switch i) in Fabric **120**. In some cases, Li_Model **272** can be normalized or formatted in a manner that is compatible with the respective network device. For example, Li_Model **272** can be formatted in a manner that can be read or executed by the respective network device. To illustrate, Li_Model **272** can included specific identifiers (e.g., hardware plane identifiers used by Controllers **116** as classifiers, etc.) or tags (e.g., policy group tags) that can be interpreted by the respective network device. In some cases, Li_Model **272** can include JSON objects. For example, Li_Model **272** can include JSON objects to represent rules, filters, entries, scopes, etc.

The format used for Li_Model **272** can be the same as, or consistent with, the format of Ci_Model **274**. For example, both Li_Model **272** and Ci_Model **274** may be based on JSON objects. Similar or matching formats can enable Li_Model **272** and Ci_Model **274** to be compared for equivalence or congruence. Such equivalency checks can aid in network analysis and assurance as further explained herein.

Switch Logical Configuration Generator **316** can also perform change analysis and generate lint events or records for problems discovered in L_Model **270**A and/or LR_Model **270**B. The lint events or records can be used to generate alerts for a user or network operator.

Policy Operator **318** can receive Ci_Model **274** and Hi_Model **276** for each switch from Unified Collector **314**, and Li_Model **272** for each switch from Switch Logical Policy Generator **316**, and perform assurance checks and analysis (e.g., security adherence checks, TCAM utilization analysis, etc.) based on Ci_Model **274**, Hi_Model **276**, and Li_Model **272**. Policy Operator **318** can perform assurance checks on a switch-by-switch basis by comparing one or more of the models.

Returning to Unified Collector **314**, Unified Collector **314** can also send L_Model **270**A and/or LR_Model **270**B to Routing Policy Parser **320**, and Ci_Model **274** and Hi_Model **276** to Routing Parser **326**.

Routing Policy Parser **320** can receive L_Model **270**A and/or LR_Model **270**B and parse the model(s) for information that may be relevant to downstream operators, such as Endpoint Checker **322** and Tenant Routing Checker **324**. Similarly, Routing Parser **326** can receive Ci_Model **274** and Hi_Model **276** and parse each model for information for downstream operators, Endpoint Checker **322** and Tenant Routing Checker **324**.

After Ci_Model **274**, Hi_Model **276**, L_Model **270**A and/or LR_Model **270**B are parsed, Routing Policy Parser **320** and/or Routing Parser **326** can send cleaned-up protocol buffers (Proto Buffs) to the downstream operators, Endpoint Checker **322** and Tenant Routing Checker **324**. Endpoint Checker **322** can then generate events related to Endpoint violations, such as duplicate IPs, APIPA, etc., and Tenant Routing Checker **324** can generate events related to the deployment of BDs, VRFs, subnets, routing table prefixes, etc.

FIG. **3**C illustrates a schematic diagram of an example system for static policy analysis in a network (e.g., Network Environment **100**). Static Policy Analyzer **360** can perform assurance checks to detect configuration violations, logical lint events, contradictory or conflicting policies, unused contracts, incomplete configurations, etc. Static Policy Analyzer **360** can check the specification of the user's intent or intents in L_Model **270**A to determine if any configurations in Controllers **116** are inconsistent with the specification of the user's intent or intents.

Static Policy Analyzer **360** can include one or more of the Operators **310** executed or hosted in Assurance Appliance **300**. However, in other configurations, Static Policy Analyzer **360** can run one or more operators or engines that are separate from Operators **310** and/or Assurance Appliance **300**. For example, Static Policy Analyzer **360** can be a VM, a cluster of VMs, or a collection of endpoints in a service function chain.

Static Policy Analyzer **360** can receive as input L_Model **270**A from Logical Model Collection Process **366** and Rules **368** defined for each feature (e.g., object) in L_Model **270**A. Rules **368** can be based on objects, relationships, definitions, configurations, and any other features in MIM **200**. Rules **368** can specify conditions, relationships, parameters, and/or any other information for identifying configuration violations or issues.

Moreover, Rules **368** can include information for identifying syntactic violations or issues. For example, Rules **368** can include one or more rules for performing syntactic checks. Syntactic checks can verify that the configuration of L_Model **270**A is complete, and can help identify configurations or rules that are not being used. Syntactic checks can also verify that the configurations in the hierarchical MIM **200** are complete (have been defined) and identify any configurations that are defined but not used. To illustrate, Rules **368** can specify that every tenant in L_Model **270**A should have a context configured; every contract in L_Model **270**A should specify a provider EPG and a consumer EPG; every contract in L_Model **270**A should specify a subject, filter, and/or port; etc.

Rules **368** can also include rules for performing semantic checks and identifying semantic violations or issues. Semantic checks can check conflicting rules or configurations. For example, Rule**1** and Rule**2** can have aliasing issues, Rule**1** can be more specific than Rule**2** and thereby create conflicts/issues, etc. Rules **368** can define conditions which may result in aliased rules, conflicting rules, etc. To illustrate, Rules **368** can specify that an allow policy for a specific communication between two objects can conflict with a deny policy for the same communication between two objects if the allow policy has a higher priority than the deny policy, or a rule for an object renders another rule unnecessary.

Static Policy Analyzer **360** can apply Rules **368** to L_Model **270**A to check configurations in L_Model **270**A and output Configuration Violation Events **370** (e.g., alerts, logs, notifications, etc.) based on any issues detected. Configuration Violation Events **370** can include semantic or semantic problems, such as incomplete configurations, conflicting configurations, aliased rules, unused configurations, errors, policy violations, misconfigured objects, incomplete configurations, incorrect contract scopes, improper object relationships, etc.

In some cases, Static Policy Analyzer **360** can iteratively traverse each node in a tree generated based on L_Model **270**A and/or MIM **200**, and apply Rules **368** at each node in the tree to determine if any nodes yield a violation (e.g., incomplete configuration, improper configuration, unused configuration, etc.). Static Policy Analyzer **360** can output Configuration Violation Events **370** when it detects any violations.

FIG. **4** illustrates an example configuration **400** for a network assurance platform **434**. The network assurance platform **434** can run the assurance operator **402** on each Leaf **104** to generate and emit fault codes from the Leafs **104**. In some cases, the assurance operator **402** can be, for example, one or more operators from the operators **310** illustrated in FIG. **3**A. The fault codes can represent errors, such as hardware errors. The assurance operators **402** can send the raw faults **404** to the logical policy enrichers **406**.

The logical policy enrichers **406** can map the hardware identifiers (e.g., scope, pcTag, etc.) to the logical policy entity defined in the fabric configuration (e.g., ACI fabric configuration). For example, the logical policy enrichers **406** can map the hardware identifiers to particular tenants, EPGs, application profiles (APs), contracts, etc. The logical policy enrichers **406** can generate indexed faults **408** based on the mappings, and send the indexed faults **408** to tenant aggregators **418**, **420**, **422**, **424**. In some cases, the indexed faults **408** can be transmitted to the aggregators as pairs such as key and tag pairs. Each key can represent a specific dimension, such as a tenant, a contract, an application profile, and EPG pair, etc.

The aggregators **418**, **420**, **422**, **424** can represent an aggregation layer. In some cases, the aggregators **418**, **420**, **422**, **424** can be specifically set to aggregate along a predetermined dimension, such as tenant (e.g., aggregator **418**), contract (e.g., aggregator **420**), application profile (e.g., aggregator **422**), EPG pair (e.g., aggregator **424**), etc. The aggregators **418**, **420**, **422**, **424** can generate faults along a specific dimension, such as faults by tenant **410**, faults by contract **412**, faults by application profile **414**, faults by EPG pair **416**, etc.

The network assurance platform **434** can then generate and/or store visualization data for specific dimensions. For example, the network assurance platform **434** can maintain tenant error visualization **426**, contract error visualization **428**, application profile error visualization **430**, EPG pair error visualization **432**, and so forth. The visualizations can provide hardware-level visibility of errors along specific dimensions in an SDN, such as an ACI network. Moreover, the tenant error visualization **426**, contract error visualization **428**, application profile error visualization **430**, EPG pair error visualization **432** can be stored in one or more respective storage locations, such as databases or storage servers.

FIG. **5**A illustrates an example flowchart for a network assurance model. At step **500**, the method involves data collection. Data collection can include collection of data for operator intent, such as fabric data (e.g., topology, switch, interface policies, application policies, endpoint groups, etc.), network policies (e.g., BDs, VRFs, L2Outs, L3Outs, protocol configurations, etc.), security policies (e.g., contracts, filters, etc.), service chaining policies, and so forth. Data collection can also include data for the concrete, hardware model, such as network configuration (e.g., RIB/FIB, VLAN, MAC, ISIS, DB, BGP, OSPF, ARP, VPC, LLDP, MTU, QoS, etc.), security policies (e.g., TCAM, ECMP tables, etc.), endpoint dynamics (e.g., EPM, COOP EP DB, etc.), statistics (e.g., TCAM rule hits, interface counters, bandwidth, etc.).

At step **502**, the method can involve formal modeling and analysis. Formal modeling and analysis can involve determining equivalency between logical and hardware models, such as security policies between models, etc.

At step **504**, the method can involve smart event generation. Smart events can be generated using deep object hierarchy for detailed analysis, such as: Tenant, Leaf, VRFs, Rules; Filters, Routes, Prefixes, Port Numbers.

At step **506**, the method can involve visualization. Formal models can be used to identify problems for analysis and debugging, in a user-friendly GUI.

FIG. **5**B illustrates an example method for fault code aggregation. At step **520**, the assurance operators **402** obtain respective fault codes corresponding to one or more network devices in a network (e.g., Leafs **104**). At step **522**, the logical policy enrichers **406** map the one or more network devices and/or the respective fault codes to respective logical policy entities defined in a logical policy model of the network, to yield fault code mappings. The logical policy model can be a model of the fabric and/or network generated based on the SDN or ACI configurations.

At step **524**, the aggregators **418**, **420**, **422**, **424** aggregate one or more of the fault code mappings along respective logical policy dimensions in the network to yield an aggregation of fault codes across respective logical policy dimensions. At step **526**, the network assurance platform **434** presents, for each of the respective logical policy dimensions, one or more hardware-level errors along the respective logical policy dimension. In some cases, the network assurance platform **434** can generate visualization data or interface data for presenting the one or more hardware-level errors along the respective logical policy dimension. Such data can be based on the aggregation of fault codes across the respective logical policy dimensions.

The disclosed technology addresses the need in the art for assuring tenant forwarding in a network environment. The present technology involves system, methods, and computer-readable media for network assurance in layer 1, layer 2 and layer 3 of the networked environment. The present technology also involves system, methods, and computer-readable media for network assurance for internal-internal (e.g., inter-fabric) forwarding and internal-external (e.g., outside the fabric) forwarding in the networked environment. In some examples, the network assurances can be in non-fabric networked environments. The network assurance can be performed using logical configurations, software configurations and/or hardware configurations.

As discussed above, certain embodiments are directed to the creation of policies that will define how Endpoints **122** can communicate with each other via the Leafs **104** and the Spines **102** with Fabric **120**. Embodiments disclosed herein include the creation and dissemination of five levels of instruction information discussed above with respect to FIGS. **2**D that will configure Leafs **104** and Spines **102** to facilitate that communication. Each level can include a change in content and/or format, although this need not always be the case.

By way of non-limiting example, FIG. **7** illustrates example configurations in networked environment **700**. Tenant Configuration **740** (e.g., an L_Model **270**A configuration) can have VRF**1** configured with BD**1**. BD**1** can have one or more configured subnets (e.g., 10.1.*, 100.2.*, etc.). Subnets can be designated either private or public. In some examples, subnets can have a default designation of private. In this example, subnet 100.2.* has been made public (e.g., accessible from outside Fabric **120** and Networked Environment **700**). Subnet 100.2.* can be associated with Web Server **746**. For example, Web Server **746** can provide, via subnet 100.2.*, access to one or more web services (to devices) within fabric **120** and outside of fabric **120** via Network Device **114**.

In order for communication to and from Web Server **746** to be facilitated, Tenant Configuration **740** must be sent from Controller **116** to the Leafs **104** and Spines **102** of Fabric **120**. Public subnet 100.2.*, must also be leaked to an external device (e.g., Network Device **114**) from a border leaf (e.g., Leaf N). For tenants to communicate outside the Fabric **120**, the external network device (e.g., Network Device **114**) must leak subnets (e.g., 175.*) to the border leaf (e.g., Leaf N). The leaked external subnets (e.g., learned routes) can then be propagated to the L3 tables of the Leafs **104** and Spines **102** of the Fabric **120**.

VRFs can operate in the Layer 3 domain and can enable multiple instances of a routing table to coexist on the same router (e.g., Leafs **104** and Spines **102**, etc.) at the same time. Since the routing instances are independent, the same or overlapping IP addresses can be used across VRFs without conflict.

BDs can operate as a Layer 2 forwarding construct within the fabric and can enable bidirectional flow of traffic between a Layer 2 bridged network and Layer 3 routed network traffic. Each BD can reside in a VRF. Each BD can also define one or more subnets. IP address in the defined subnets can belong to the specified BD.

A Logical Group (EPG) can be a managed object that is a named logical entity and contains a collection of endpoints. Endpoints can be devices that are connected to the network directly or indirectly (e.g., servers, virtual machines, network-attached storage, etc.). Each EPG can be assigned to a BD. EPGs can have an address (e.g., identity), a location, attributes (e.g., version or patch level), and can be physical or virtual. Endpoint membership in an EPG can be dynamic or static. Subnets can also be defined at the EPG.

L3out can be a construct to extend Layer 3 for external communication (e.g., outside the fabric and/or network environment). L3out can be bound to a VRF. L2out can be a construct to extend the Layer 2 for external communication (e.g., outside the fabric and/or network environment). L2out can be bound to a BD.

Controller **116**, once configured, can push the L_Model **270**A/B to the Leafs **104** and Spines **102** of the Fabric **120**. In some cases, the L_Model **270**A/B can be pushed to all Leafs **104** and Spines **102** of the Fabric **120**. In other cases, portions of the L_Model **270**A/B can be pushed to the Leafs **104** and Spines **102** of the Fabric **120** that are responsible for routing and forwarding data that are consistent with the L_Model **270**A/B. For example, when BD**1** defines subnet 10.1.1.*, the Leafs **104** that are configured to that BD (e.g., responsible for transmitting data with subnet 10.1.1*) can receive the L_Model **270**A/B configuration related to BD**1**.

The L_Model **270**A/B can be used to populate forwarding and routing tables (L3), VLAN tables (L2), interfaces (L1) and endpoint table (L2 and L3) at Leafs **104** and Spines **102** of the Fabric **120**. For example, when BD**1** defines subnet 10.11*, the LPM table can populate an entry for the subnet and a destination to which incoming packets are to be routed (e.g., Leaf **3**).

In some examples, the LPM table can be part of the forwarding table. The LPM table can specify one or more a subnets with a destination address matching more than one entry in the LPM table. The most specific of the matching table entries—the one with the longest subnet mask can be selected. The LPM table can also include information relating to subnets, static routes, dynamic (learned) routes, L3 interfaces, and L3 loopbacks. Populated LPM tables in FIG. **7** include tables **742**, **748**, **1802** and **1806**, which are Ci_Models.

Each Leaf **104** in Fabric **120** can have a Layer**3** (L3) Table (e.g., Longest Prefix match (LPM) Table). For example, L3 Table **742** can reside on Leaf **2** and L3 Table **748** can reside on Leaf N. The L3 tables can include a listing of subnets and next hops. For example, when a tenant of Leaf N requests to access Web Server **746**, Leaf N can look up in L3 Table **748** the subnet associated with Web Server **746** (e.g., 100.2.*) and determine the next hop (e.g., Leaf **2**). Accordingly, Leaf N can direct the packets from the tenant, to Leaf **2** via one of the Spines.

In other examples, devices outside Fabric **120** can request access to public Web Server **746**. In these examples, the border leaf (e.g., Leaf N) can leak the public subnet (e.g., 100.2.*) to the external network device (e.g., Network Device **114**). The external network device can maintain routing and forwarding tables (e.g., Table **744**) where the leaked subnet information is stored. When a device outside Fabric **120** requests access to Web Server **120**, Network Device **114** can determine where to forward the request by Table **744**. The request will then be routed to the border leaf (e.g., Leaf N). The request can then be routed to the proper destination by the L3 tables of the Leafs and Spines.

In other examples, tenants within Fabric **120** can access devices external to the fabric (through the border leaf to which the external network is connected). For example, a tenant (e.g., EndPoint **4**) can request access to devices external to Fabric **120**, such as subnet 175.*. L3 Table **742** can determine that the next hop in accessing the external device is via Leaf N (e.g., subnet 175.*→Leaf N). This learned route is leaked from Network Device **114** to Border Leaf N, which is then propagated to the other leafs and spines of the fabric as needed. Border Leaf N can then route the request external to the fabric via next hop Network Device **114** (e.g., from L3 Table **748**).

Networked Environment **700** can also include routing and forwarding through security contracts (e.g., **750**) between logical groups, Layer 3 loopbacks and Layer 3 interfaces. While not shown, the L3 tables also include the Layer 3 loopback and Layer 3 interfaces.

The above instructions, and other instructions, are deployed by the Controllers **116** as L_Models **270**A/B and executed by the conversion into Ci_Model **274** and Hi_Model **276** as the individual Leafs **104** and Spines **102**. Network assurance is a process by which the various creation and propagation of the L, C and H models, and related content, have been properly programmed, deployed, created etc. By way of non-limiting example, single level checks can be performed at the logical, software and/or hardware models by verifying the consistency of the models. Checks can also be performed by checking whether models were properly converted into other levels, e.g., whether the Leafs **104** and Spines **102** properly converted the L_Model **270**A/B into Ci_Model **274** (logical to concrete checks) and Ci_Model **274** into Hi_Model **276** (concrete to hardware checks).

Network assurance can be verified by Assurance Appliance **300**. Appliance **300** can poll devices (e.g., Spines **102**, Leafs **104**, Controller **116**) of the networked environment (e.g., **100**, Fabric **120**) for the resident L, H and C Model configurations. For example, the application can poll Controllers **116** for L_Model **270**A/B configurations and Leaf **104** and Spines **102** for Ci_Model **274** and Hi_Model **276** configurations. After receiving one or more L, C and H Model configurations from the one or devices (e.g., Spines **102**, Leafs **104**, Controller **116**), Appliance **300** can perform one or more verifications using Checker **620** shown in FIG. **6**, which can operate in the manner discussed with respect to FIG. **3**B. It is to be understood that activity undertaken by one of Appliance **300** or Checker **620** can be undertaken by the other.

Checker **620** can be a component of Appliance **300**. Checker **620** can receive as input one or more configurations (e.g., received at Appliance **300** through polling via Unified Collector **314**), as well as other inputs as may be provided by Network **100** and/or Fabric **120**. In some examples, one more L_Model **622** configurations (e.g., L-Model **270**A/B) as provided by Controller **116** can be received as input. Similarly, reporting Leafs **104** and Spines **102** provide, and Checker **620** receives as input, one or more C_Model **624** configurations (e.g., Ci_Model **274**) and one or more H_Model **626** configurations (e.g., Ci_Model **276**). Other data from components of the Fabric **120** and/or Network **100** may also be received at Checker **620**.

One type of check is a single level consistency check, in which a particular received model **622**/**624**/**626** is checked to confirm that the intent of the operator as originally programmed is represented and properly configured in the model. For example, Checker **620** can perform consistency checks on the L_Model configuration **622**. For example, performing syntactic analysis (e.g., configuration, setup, typographical, etc.) on the L_Model configuration **622**. The consistency checks can determine if the intent of the operator, when creating the configuration, is represented in the L_Model configuration **622**.

A non-limiting example of a Layer 1 consistency check on L_Model configuration **622** is EPG deployed on an 'admin down' interface. This check can read the EPG deployment information and Interface Admin status from the L-Model. The EPG deployment information can identify the Leaf and interface where the EPG is physically deployed, and if properly deployed would match the Leaf and interface in the Interface Admin Status information. If the status is found to be 'admin down' the check may fail.

A non-limiting example of a Layer 2 check is overlapping encap VLANs on a switch. This check can read the EPG deployment information and Interface Port Policies from the L-Model to obtain the leaf, interface and encap VLAN. The EPG deployments can be grouped on a leaf by leaf basis. Within each such (leaf) group, the check can look for two distinct EPGs having the same encap VLAN. When such a pair is found, the check may fail if the pair are on the same interface. In other examples, the check can search interfaces on which the matching EPG pair for Interface Port Policies information gathered from the L-model. The check may fail if the VLAN scope of both the ports is marked as global.

A non-limiting example of a Layer 3 check is overlapping subnets due to cross-VRF contracts. This check can read the BD (subnets and VRF associated), EPG (subnets and BD association), and Contract information from the L-model. Within the set of Contracts the check can search for a Contract satisfying the cross VRF property as follows: VRF of BD of provider EPG of contract, namely provider VRF, and VRF of BD of consumer EPG of contract, namely consumer VRF are not the same VRFs. When such a contract is found, the check determines the consumer subnets (EPG subnets as well as consumer EPG's BD subnets) and provider subnets (EPG subnets). The checks may fail when any of the consumer subnets overlaps with any of the provider subnets.

Similarly, one or more C_Model **624** configurations (e.g., the Ci_Models **274** from the reporting Leafs **104** and Spines **102**) can be received as an input and Checker **620** can perform consistency checks on any and all C_Model **624** configurations. Non-limiting examples of consistency checks, and how they are preformed, are as follows:

A non-limiting example of a Layer 1 check is Virtual Port Channel (VPC) consistency. The check can read the VPC state information from each Leaf. The check may fail if some interfaces on one leaf are in VPC mode, but no interfaces on the VPC peer leaf are in VPC mode.

A non-limiting example of a Layer 2 check is EPG VLAN (FD-VLAN) and BD VLAN (BD-VLAN) relationship consistency. The check can read the VLAN table information of a Leaf. The check can also search an FD-VLAN, such that its parent BD-VLAN does not include in the list of its children—if found, however, the check may fail. In other examples, the check may fail if an identified FD-VLAN does not indicate the BD-VLAN as the parent.

A non-limiting example of a Layer 3 check is Learned route distribution and next hop consistency. The check can read the LPM table information of all Leafs. The check may fail when a route is learned on some border leaf via an L3out but the route is not present on all of the other leafs where the L3out's VRF is deployed. In other examples, the check may fail when the next hops of the route on non-border leafs does not contain the border leafs.

There is no specific need for a separate H_Model consistency check, as this would be encompassed by the consistency check of the corresponding C_Model; any absence of issues in the C_Model checks by extension represents a lack of issues in the corresponding H_Model. However, the application is not so limited, and Checker **620** can perform an H_Model consistency check consistent with the methodologies discussed herein.

Another type of check is a model-to-model check. Such a check confirms that the Leafs **104** and Spines **102** properly converted an L_Model **270**A/B into a Ci_Model **274**, and/or a Ci_Model **274** into an Ci_Model **276**.

For an L-to-C model ("L-C") check, a specific Leaf or Spine provides a Ci_Model as C_Model **624** and Controller **116** provides an L_Model **622**. Checker **620** can determine whether the specific Ci_Model was properly generated from the L_Model **622**. Checker **620** first takes the L_Model **622** and generates the corresponding local Li_Model for that particular Leaf or Spine; this can be performed by Switch Logical Policy Generator **316** as described with respect to FIG. **3**B, for which the corresponding generated Li_Model is shown in FIG. **3** as Li. Since the particular Ci_Model and the corresponding generated Li_Model are in different formats, checker **620** converts one or both into the same format ("common format"). This format may be the native format of the Li_Model or the Ci_Model (in which case only one of the models would need to undergo format conversion), but can be a format different from both. Non-limiting examples of the common format is JSON objects, flattened list, strings, XML, common table, etc.

As discussed above, a particular Ci_Model **274** may have different content than the Li_Model **272** from which it was based, such that there will be overlapping fields of content between the models. The content difference reflects in part that Li_Model represents instructions of operator intent and the Ci_Model represents actual implementation of that intent, and thus the Ci_Model can include content regarding actual implementation. Checker **620** can extract (at least some of the) content from the overlapping fields from the common format version of the Ci_Model and the corresponding generated Li_Model and compares them relative to each other. If the extracted content from the overlapping fields matches, then the content was properly incorporated when the corresponding Ci_Model was created. If the extracted content from the overlapping fields do not match, then an error is generated, for example, an error that prevented the proper creation or population of the corresponding Ci_Model. The error could have occurred in a number of different ways, for example, in the L-to-C conversion, or that the Ci_Model is outdated (perhaps the updated L_Model never having been received or converted at all); the application is not limited to the nature of the error.

For a C-to-H model ("C-H") check, a specific Leaf or Spine provides its specific Ci Model **624** and Hi Model **626**. Checker **620** can determine whether the Hi Model was properly generated from the Ci_Model. Since the particular Ci_Model and the Hi_Model are in different formats, checker **620** can convert one or both into a common format. This format may be the native format of the Hi_Model or the Ci_Model (in which case only one of the models would need to undergo format conversion), but can be a format different from both. The common format of the C-H level check may be the same or different from the format used in the L-C level checks. Non-limiting examples of the common format is JSON objects, flattened list, strings, XML, common table, etc.

As discussed above, a particular Ci_Model **274** may have different content than the corresponding Hi_Model **276** from which it was based, such that there will be overlapping fields of content between the models information. Checker **620** can extract (at least some of) the content from the overlapping fields from the common format version of the Ci_Model **624** and the corresponding Hi_Model **626** and compares them relative to each other. If the extracted content from the overlapping fields matches, then the content was properly incorporated when the corresponding Hi_Model was created. If the extracted content from the overlapping fields does not match, then some error prevented the proper creation of the corresponding Hi_Model. The error could have occurred in a number of different ways, for example, in the C-to-H conversion, or that the Hi_Model is outdated (perhaps the Leaf **104** simply never performed the conversion in the first place); the application is not limited to the nature of the error.

In response to no discrepancies in the consistency or model-to-model conversion check, Checker **620** can output an informational event **628**. In response to one or more discrepancies Checker **620** can output an error event **628** (e.g., of varying severity depending on the discrepancy).

FIG. **9** illustrates an example flowchart for an example network assurance of model-to-model checks of a network environment. The method shown in FIG. **9** is provided by way of example, as there are a variety of ways to carry out the method. Additionally, while the example method is illustrated with a particular order of sequences, those of ordinary skill in the art will appreciate that FIG. **9** and the sequences shown therein can be executed in any order that accomplishes the technical advantages of the present disclosure and can include fewer or more sequences than illustrated.

Each sequence shown in FIG. **9** represents one or more processes, methods or subroutines, carried out in the example method. The sequences shown in FIG. **9** can be implemented by an application in a network environment such as network environment **100** shown in FIG. **1**A and **1**B. The application can be present on Appliance **300** and/or Checker **620**, although the application is not so limited.

At sequence **910**, the various models (e.g., L_Model, C_Model, and/or H_Model) to be checked are received. For example, each Controller **116** in the Fabric **120** can send to the application (e.g., Assurance Appliance **300** and/or Checker **620**) one or more L_Models **270**A/B, and each Leaf **104** and Spine **102** sends its corresponding Ci_Model **274**, and Ci_Model **276**. In another example, some but not all of the L_Model, C_Model, and/or H_Model configurations are provided and/or received. Those received models will include information content, at least some of which will be subject to the validation process.

At sequence **920**, the application can convert two received models into a common format (i.e., one model is converted into the format of the other so they are the same, or both models are converted into the same new format). In some examples, the common format can be the common model (e.g., that the configuration was original entered in by the operator).

At sequence **930**, the application can validate the received information by comparing content from relevant overlapping fields in the common format of the two models. A match in content represents that, at least for that content, the originating Leaf **104** or Spine **102** properly converted one level of model into the next level of model. For example, the logical model (e.g., L_Model) received from the controller was properly converted into the concrete model (e.g., C_Model). A discrepancy indicates some error in relation to the deployment or creation of the models.

At sequence **940**, an event is generated. For example, when the validations are consistent the application can generate an information event. In other examples, when one or more of the validations are not consistent the application can generate an error event. The severity of the error event can at least be determined based on which validation is inconsistent and which device had the inconsistency (e.g., production device, test device, access point, border leaf, etc.).

The above methodology reflects the overall steps for model-to-model checks. Individual types of model-to-model checks may include additional steps, modify certain steps, or omit certain steps. Non-limiting examples of such individual checks are set forth in other sections herein.

In the above embodiments, the local Li_Model **272** is not requested or provided to Checker **620**, as the configuration and/or level checks that include the L_Model **270**A/B would encompass any specific checks on local Li_Model **272**. However, the application is not so limited, and a local Li_Model **272** can be an input to Checker **620** and checked consistent with the methodologies discussed above.

In the above embodiments, there is no need for a separate L-to-H model ("L-H") check, as this would be encompassed by the combined results in the L-C and C-H checks; the absence of discrepancies in the L-C and C-H checks by extension represents a lack of discrepancies between L and H. However, the application is not so limited, and Checker **620** can perform an L-H level check consistent with the methodologies discussed above.

Consistency checks may be universal to an entire model, in that all content of the model is checked. In other examples, only some content of the model may be checked, and in particular topic specific content. By way of non-limiting example, a Layer 2 specific check may only examine content in the model that is specific to Layer 2 operations, while a Layer 3 specific check examines content in the model that is specific to Layer 3 operations.

In some examples, model-to-model checks may be universal to all content of the model, in that all content (at least all content found in overlapping fields of the models that are to be compared) can be compared to identify which specific fields have matches or discrepancies. To the extent that certain specific topic checks are of interest, the check can simply consult the resulting overall comparison to examine the relevant fields. By way of a non-limiting example, the L and the C level may have 50 overlapping fields of content, but a first particular check may only require consideration of three (3) of them, while a second particular check only requires consideration of two (2) of them. Each topic specific check can consult the results of the comparison search for the needed specific fields. In this way, the comparison can precede the request for a topic specific check.

In other examples, some content of the models may be compared, and in particular topic specific content. For example, as discussed in more detail with respect to individual checks below, some checks are targeted to specific information with respect to a specific topic. In such cases, the comparison may not include or consider all overlapping fields, and would instead be limited to the overlapping fields of interest. By way of non-limiting example, a Layer 2 specific check may only compare content of overlapping fields in specific to Layer 2 operations. The types of information of interest relative to a particular check can be predefined in the application (e.g., **300**), although the application is not so limited. In this way, the request for a topic specific check can precede the comparison, and the comparison can be limited only to the topics of interest.

Topic specific checks may be self-contained or overlap. Specifically, as discussed above different topic checks may examine different overlapping fields within the models. Some of these fields may be common to different checks. By way of a non-limiting example and as discussed below, Layer 2 checks for both BD deployment and an EPG deployment, both of which examine the information about the VLAN; thus two different checks include consideration of the similar content. If the checks are self contained, then each check would examine the relevant content regardless of other prior/future checks; thus in the example the VLAN would be checked independently in both the BD deployment and an EPG deployment check. In the other examples, if a common field has already by examined by a prior check, then a subsequent check can rely upon those results rather than conduct an independent examination; thus if the BD check shows that the VLAN information is as expected, then a subsequent EPG check can adopt those results rather than again/separately examine the VLAN information.

In the above embodiments, the results of the check are either a match or a discrepancy. However, the application is not so limited. There can be a predefined range of acceptable variation between compared content as to be acceptable or otherwise consistent with expectations. There could be some content for which a particular discrepancy is less important that another type of discrepancy. The application is not limited to the manner in which Checker **620** evaluates the existence, nature or impact of discrepancies.

Although the above checks are discussed with respect to specific Leafs **104** and Spines **102**, it is to be understood that these checks can be performed on all or some Leafs **104** and Spines **102**. Such checks could be in response to simply receiving the models, e.g., a C_Model and H_Model are received, and thus a C-H check is performed. In other examples, specific Leafs **104** and/or Spine **102** could be polled for information and the check confined to request information. The application is not limited to the manner in which information for checks are requested or received, or what triggers Checker **620** to institute a particular check.

Tenant Forwarding Event Generation

As shown above, FIG. **6** also illustrates the generation of an Event **628**. Events can be generated in response to Checker **620** performing a check on one or more inputs (e.g., **622**, **624**, **626**, **630**). Events can be informational events and error events. Informational events are generated in response to no inconsistencies or discrepancies found during the check of the inputs. The information event can include the check performed, the devices checks, the time checked, the result of the check, etc. The informational (and error) events can be stored in a memory/database accessible by Appliance **300**.

Historically stored events can be used in a predictive manner. By way of non-limiting example, the cause and effect (and particularly the failure) of prior configurations and checks of those configurations can be stored and referred to. Before changes are made to the Fabric **120** or networked environment with a newly proposed configuration, the system can consult with the historical data for instances of the same or similar configurations and any resulting positive or adverse effects of the same. The system can thus predict if the newly proposed configuration will adversely affect the network based on previous configurations that are the same or similar in nature. Similarly, the historical events can also be used to predict changes that have recently taken affect that could cause issues.

The error events can be generated in response to inconsistencies or discrepancies found during the check of the inputs (e.g., L_Model, C_Model, H_Model, etc.). The error events can have different levels of severity, for example, warning, minor, major, critical, etc. A warning severity can be a potential problem in the future, such as, not using best practices, or events that are of interest to the operator. A minor severity can be a low impact problem, for example, does not affect production devices, operation not affected, etc. A major can be a high impact problem, for example, operation is affected, but is still operational, (e.g., production devices dropping some packets, etc.). A critical error is a serious failure that usually prevents normal operation of devices and requires an immediate fix, for example, failure of border leaf, production devices, etc.

Each event can include a mnemonic (event code), a description of the error, remediation steps, affected objects (e.g., VRF), secondary affected objects (e.g., BD and EPG linked to affected VRF), severity level, number of checks, etc. When an error has occurred with an affected object, each secondary affected object can be checked for errors. For example, when a VRF has an issue and an error event is generated, the secondary objects of the VRF (linked BDs, EPGs, etc.) can be checked for errors. In some examples, the error might be generated at a higher level (e.g., VRF), but the cause of the error could be from a lower level (e.g., BD, EPG, etc.). By checking secondary objects and determining the actual cause of the error, remediation can be more efficient and effective.

In some examples, the remediation steps can be transmitted to the operator. In other examples, one or more of the devices in the network environment or fabric can automatically perform the remediation steps. In some examples, Appliance **300** can perform the remediation steps. In other examples, the remediation can require a vendor and the operator can be notified to contact the vendor.

Validation of Layer 1

From the perspective of deployment the operator can define in the L Model **270**A instructions as to particular Leafs **104** or Spines **102** regarding Layer 1 operability. This can include whether a physical link (e.g., port) is set to active or down, a software link (e.g., port) is active or down, and a configured check to see if the interface is configured or not configured (e.g., access policy configured, etc.). Leafs **104** and Spines **102** can receive the L_Model **270**A, convert the relevant content into Ci_Model **274**, and then execute on the instructions to institute the configurations and set the physical link, software links and interfaces in the manner instructed. Leafs **104** and Spines **102** then update their respective Ci_Models **274** to reflect the status of the physical, software links, interfaces and any combination thereof.

Network assurance of Layer 1 physical interfaces is directed to Appliance **300** and/or Checker **620** confirming that the configurations are present and the links are set as instructed. The Layer 1 checks can be a physical link check (e.g., active or down), software link check (e.g., active or down) and a configured check (e.g., configured or not configured). For Layer 1 to be actively configured, each of the three controls should be configured properly (e.g., physical link up, software link up, access policy configured). In other examples, Layer 1 may not be actively configured and the three controls can be up, down and not configured.

The physical link check can determine if the network interfaces (e.g. of Leafs **104** and Spines **102**) have a physical connection (e.g., cable attached, etc.). The Checker **620** receives the Ci_Model from a particular individual Leaf **104** or Spine **102**, and identifies in the Ci_Model the reported status of whether the physical link is active or down. Checker **620** can also poll the software of the particular individual Leaf or Spine that monitors the hardware status to determine if the actual state of the physical link is as reflected by the Ci_Model, such as by issuing commands on the command line interface of a device (e.g., ethtool, ifconfig, etc.). The physical link is validated when the states match, and a discrepancy exists when the states do not (e.g., the polled state says the link is active but the reported state shows it is down, or vice-versa).

The software link check can determine when the physical link (e.g., port) is up or down at the software level (e.g., firmware, application, etc.). The methodology tracks that of the physical link check above, save that Checker **620** polls the software of the particular individual Leaf or Spine that monitors the software status to see if the actual state of the software link is as reflected by the Ci_Model, such as ports of a device having been brought up or down through software (e.g., a command line interface (or GUI) of the device). The software link is validated if the states match, and a discrepancy exists if they do not (e.g., the polled state says the link is active but the reported state shows it is down, or vice-versa).

The configured check can determine when the interface is configured (e.g., has an access policy, etc.). Access policies can govern the operation of switch access ports that provide connectivity to resources such as storage, compute, Layer 2 and Layer 3 (bridged and routed) connectivity, virtual machine hypervisors, Layer 4 to Layer 7 devices, etc. Access policies can enable the configuration of, but not limited to: port channels and virtual port channels, protocols such as LLDP, CDP, or LACP, speed, STP properties, and features such as monitoring or diagnostics. Access policies can include common objects including, but not limited to: leaf profiles, leaf policies, interface profiles, interface policies, AEP, VLAN pools, physical domain (physdom), VMM domain, hypervisor, etc. Referring now to FIG. **3**D, the particular check is an L-Model level consistency check, for which checker **620** checks to confirm that the switch profile **382** and interface profile **384** are present, populated and properly linked **386**, and that the interface profile **384** is properly linked **386** to the global profiles **388**. Checks of global profiles and other content can occur at other layers.

FIG. **8** illustrates an example flowchart for an example network assurance of Layer 1 physical interfaces. The method shown in FIG. **8** is provided by way of example, as there are a variety of ways to carry out the method. Additionally, while the example method is illustrated with a particular order of sequences, those of ordinary skill in the art will appreciate that FIG. **8** and the sequences shown therein can be executed in any order that accomplishes the technical advantages of the present disclosure and can include fewer or more sequences than illustrated.

Each sequence shown in FIG. **8** represents one or more processes, methods or subroutines, carried out in the example method. The sequences shown in FIG. **8** can be implemented in a network environment such as network environment **100** shown in FIG. **1**A and **1**B. The application can be present on Appliance **300** and/or Checker **620**, although the application is not so limited.

At sequence **810**, the various models (e.g., L_Model, C_Model, and/or H_Model) to be checked are received. For example, one or more Leafs **104**, Spines **102** and Controllers **116** in Fabric **120** can send to the application (e.g., Assurance Appliance **300**) L_Model **270**A/B, Ci_Model **274**, and H_Model **274**. Those received models will include information content, at least some of which will be subject to the validation process. For example, Layer 1 content of interest can include the physical link status of the interfaces of the devices, the software link status of the interfaces on the devices, and any access policies for the interfaces on the devices.

At sequence **820**, the application can validate the received information. For example, the application (e.g., Assurance Appliance **300**) can validate the received information verse previously stored information. In some examples, the received physical interface status can be validated against previously stored information required to determine if the physical interface is up (e.g., active). In some examples, the received software interface status can be validated against previously stored information required to determine if the software interface is up (e.g., active). In some examples, the received access policy information can be validated against previously stored information required to determine if the access policy is present and properly configured. In some examples, checker **620** can independently obtain the information from the one or more Leafs **104**, Spines **102**, etc., and compared against the content of the models in the manner discussed above.

At sequence **830**, the application can generate an event. For example, when the validations are all successful (e.g., consistent with expectations of the validation) the application can generate an information event. In other examples, when one or more of the validations are not successful (e.g., not consistent with expectations of the validation) the application can generate an error event. The severity of the error event can at least be determined based on which validation is unsuccessful and which device was unsuccessfully validated (e.g., production device, test device, access point, border leaf, etc.).

Validation of Layer 2

Layer 2 is the protocol layer (e.g., data link layer) that can provide the functional and procedural configurations to transfer data between network entities. Appliance **300** can perform a series of network assurance checks on Layer 2 of the network environment. Layer 2 checks can include at least, for Layer 2 relevant content, a consistency check of the L_Model, an L-C check, and a C-H check, although the application is not so limited. These checks can be performed by Appliance **300** and/or Checker **620** as described above on at least the overlapping fields of content that are specific to Layer 2 operability.

The Layer 2 checks can be performed on Access Policies (e.g., common objects) and tenant trees (e.g., common objects that are pushed to leafs and spines). The tenant tree common objects can include, for each tenant, VRF, BD (bound to VRF), EPG (bound to BD). Each EPG can include deployment information (where the controller should deploy the configuration), including static binding or dynamic binding and domains. The static binding can include the leaf, card, port, and VLAN. The dynamic binding does not require further information as it is configured dynamically when required. The domains can include physical, VMM, or both. The domains and static bindings can also include deployment settings including pre-provision, immediate, lazy, etc. Once the configurations are completed (e.g., by the operator) to define the L_Model **270**A, the Controller **116** can push the L_Model **270**A/B to the appropriate Leafs **104** and Spines **102**. Appliance **300** and/or Checker **620** can then check the deployment.

The Layer 2 L_Model consistency check can include at least a syntactic analysis (e.g., configuration, setup, typographical, etc.) on the L_Model configuration. Specific content checked for Layer 2 includes by way of non-limiting example that the Access Policies are configured properly (e.g., based on the common objects), the EPG is configured properly (e.g., based on common objects), Cross EPG checks (e.g., if an EPG is using one VLAN another EPG deployed on the same Leaf should not be using the same VLAN), etc. When there are inconsistencies an event can be generated.

The Layer 2 L-C checks can include if the BD is properly deployed (e.g., semantic check). For example, some subset of BDs has been deployed on one or more of the Leafs **104**. The L-C checks can validate the subset of BDs have been properly deployed on the Leafs, for example, by utilizing the common objects (e.g., VLAN and interface). In some examples, the VLAN and interface information (e.g., C_Model) can be stored in the VLAN table of the leaf/spine.

The L-C checks can also include if EPGs are properly deployed, which similar to the BD check above examines the VLAN pair (between L_Model and C_Model) and interface pair (between L_Model and C_Model).

The Layer 2 C-H checks can be similar to the Layer 2 L-C checks, although content to be checked resides and is received from the Leafs **104** and Spines **102**. For example, the application (e.g., Appliance **300**) can receive the Ci_Model **624** and Hi_Model **626** from the one or more Leafs **104** and Spines **102**, convert to a common format and then validate the VLAN pairs and interface pairs. When there are inconsistencies between the Ci_Model and Hi_Model an event can be generated.

Another Layer 2 check is to validate VLAN assignments in the network, which is an L_Model to H_Model relative check. In some examples, the L-Model to H_Model check can be performed by a combination of the L-C and C-H checks. The checks can verify for each EPG, the same VLAN is assigned at the same interface at the L_Model, Ci_Model and Hi_Model.

Another Layer 2 check can be to validate VLAN assignments across the networked environment. This particular check is a comparison of content of the L_Model to a Distributed Virtual Switch (DVS) configuration (hereinafter "DVS_Model"). The DVS is outside of Fabric **120** and like Leafs **104** and Spines **102** also receives the L_Model **270**A/B. Checker **620** receives the L_Model **270**A/B from Controller **116** L_Model input **622** as discussed above, and also receives as a distinct input the DVS configuration from the DVS at Other input **630**. One or both of the received L_Model and/or the DVS configuration are converted into a common format, and content from relevant overlapping fields (within the models/configurations) is compared. For VLAN assignments, relevant overlapping fields can include but are not limited to: the configured VLANs for each EPG (e.g., static/physical and dynamic/virtual), and the particular VLAN IDs for dynamic/virtual EPGs.

Another Layer 2 check is VLAN provisioning on a switch or port as part of the L_Model consistency check. Appliance **300** can check that the L_Model **270**A/B received from the Controller **116** does not include overlapping VLANs. At the switch level, the Appliance **300** can determine if there are duplicate VLANs on the switch. At the port level, the Appliance **300** can determine if there are duplicate VLANs on the same ports of the switch. In the port example, there can be duplicate VLANs on different ports of the switch.

Execution of the L-DVS, L-C and C-H level checks in Layer 2 occur as discussed with respect to FIG. **9**. The various received models at sequence **910** would include information relevant to the Layer 2 analysis, such as VLAN and interface information. At sequence **920**, for each model-to-model check the application can convert the received models into a common format. At sequence **930**, the application can validate the received information by examining content from relevant fields, such as the VLAN common object and/or the interface common object of the Ci_Model. Other common objects for Layer 2 can be validated between L-DVS, L-C and C-H checks.

At sequence **940**, the controller can generate an event. For example, when the validations are consistent (e.g., consistent with expectations of the validation) the application can generate an information event. In other examples, when one or more of the validations are not consistent (e.g., inconsistent with expectations of the validation) the application can generate an error event. The severity of the error event can at least be determined based on which validation is inconsistent and which device had the inconsistency (e.g., production device, test device, access point, border leaf, etc.).

Validation of Layer 3

Appliance **300** can perform a series of checks on Layer 3 (e.g., network layer) of the network environment (e.g., network assurance). The network layer is responsible for packet forwarding including routing through intermediate routers. Layer 3 checks can include at least a consistency check of the L_Model, an L-C check, and a C-H check, although the application is not so limited. These checks are performed by Appliance **300** and/or Checker **620** as described above on at least the overlapping fields of content that are specific to Layer 3 operability.

There are a variety of Layer 3 checks that can be performed, for example, BD subnets are deployed correctly (e.g., routing on/off, IP/mask, etc.), overlapping subnet checks, L3out deployed properly, BD-L3out association, RIB is programmed properly with subnets, learned routes are properly propagated in the fabric, RIB-FIB equivalence, and Cross-VRF route leaking.

In Layer 3, a concern of the check can be integrity of deployment of the subnets. Each BD can define one or more subnets (e.g., **10.0.***). The subnets can also be defined in the Logical Groups (e.g., EPG). Each VRF (which is in Layer 3) can have a unique IP address. If another device uses the same IP address, there is not a conflict as long as the IP address is used a different VRF. In Layer 3, a common object, L3out can also be defined (for external communication). The L3out common object can define: L3 interfaces, L3out EPG, static routes and loopbacks.

Whether the BD subnets are deployed correctly can be an L-C check. The subnets for each BD (and EPG) can be resident on L_Model **270**A/B deployed by the Controller **116**. The subnets as deployed at the network devices can include a routing information base resident on the Ci_Model of the reporting Leafs **104** or Spines **102**. The application can collect the BD subnets deployed from the received L_Model and Ci_Models based on VRF assignments to define a set union (e.g., a list of BD subnet deployed without duplicates). The application can determine that the BD subnets are actually deployed at the appropriate network devices in the union (and not network devices that they should not be deployed). The BD subnets check can also include checking the BD subnets on network devices because of contracts between EPGs. The BD subnet check can determine the BD subnets points to the spine proxy and, the BD subnets have a corresponding gateway address is installed.

FIG. **10** illustrates an example flowchart for an example network assurance of Layer 3 configuration of a network environment. The method shown in FIG. **10** is provided by way of example, as there are a variety of ways to carry out the method. Additionally, while the example method is illustrated with a particular order of sequences, those of ordinary skill in the art will appreciate that FIG. **10** and the sequences shown therein can be executed in any order that accomplishes the technical advantages of the present disclosure and can include fewer or more sequences than illustrated.

FIG. **10** represents one or more processes, methods or subroutines, carried out in the example method. The sequences shown in FIG. **10** can be implemented in a network environment such as network environment **100** shown in FIG. **1**A and **1**B. The application can be present on Appliance **300** and/or Checker **620**, although the application is not so limited.

Method **1000** can begin at sequence **1010**. At sequence **1010** the various models (e.g., L_Model, C_Model, and/or H_Model) to be checked are received. For example, the one or more Leafs **104**, Spines **102** and Controllers **116** in the Fabric **120** can send to the application (e.g., Assurance Appliance **300**) L_Model **270**A/B, Ci_Model **274**, and Ci_Model **276**. Those received models include information content that can be subject to the validation process. In some examples, the information relevant to a Layer 3 check can include prefix, subnet, network, or routing data from each VRF, BD, EPG (e.g., logical group), in the network environment or fabric.

At sequence **1020**, one or more VRF containers for configuration abc (e.g., individual or multiple tables, files or the like) are created and populated for the VRFs in the received L_Model **622**. FIG. **11** illustrates example VRF containers **1100** and **1125**. While VRF containers **1100** and **1125** illustrate two different container configurations, more container configurations are realized and the example containers **1100** and **1125** are not limiting. Specific Leafs **104** under each VRF can be identified (e.g., each VRF will have one or more BD subnets, and each BD subnet will have one or more EPGs with one or more specific Leafs **104**). Example VRF container **1100** and **1125** can populated with at least the received Ci_Model **274** and the created Li_Model **272** (as previously or newly created, and accounting for security contracts as discussed below) for the specific Leafs. Each VRF container can thus include data specific to that VRF (e.g., LPM container of prefixes, subnets, networks, external routes, etc.).

At sequence **1030**, each VRF container is validated by Checker **620** and/or Appliance **300**. The Li_Models represent how the BD subnets are to be configured (e.g., per the operator intent), and the Ci_Models represent how the instructions were actually implemented (e.g., at the Leaf, Spine, etc.). The intent should match the implementation, and thus Checker **620** confirms for each VRF container that the Li_Models are consistent with the Ci_Models. A discrepancy exists if there is a mismatch in content.

A discrepancy can also exist if a model is present that should not be. For example, if only Leafs **1** and **2** are under a particular VRF, then L1_Model, Ci_Model, L2_Model and C**2**_Model models would be present in the container for that VRF. No other Li_Model or Ci_Model for another Leaf should be in the VRF container, and the presence of such a model would be a discrepancy.

FIG. **11** illustrates a deployment **1150**. For example, as shown in FIG. **11**, abc is on Leaf **1** and Leaf **2**, but not on Leaf **3**, while def is on Leaf **3**, but not Leafs **1** or **2**. As such, Checker **620** will validate the abc configuration is properly deployed on Leaf **1** and Leaf **2**, and not on Leaf **3**, and that the def configuration is properly deployed on Leaf **3** but not Leafs **1** or **2**. Checker **620** can also validate the abc configuration on Leaf **1** and Leaf **2** is consistent with the abc configuration as defined in the L_Model, and that def configuration on Leaf **3** is consistent with the def configuration as defined in the L_Model.

In some examples, Checker **620** can perform set checks. For example, the checker can perform a set difference by which after conversion to common format the Li_Model set subtracted from the Ci_Model set, and the Ci_Model set is subtracted from the L_Model set; the sets are proper when then the results of both subtractions are the same. A mismatch would indicate missing or extra information that can result in, for example, lost packets in the fabric and extra information can create, for example, security issues in the fabric (where device can access other devices they do not have permission to ask).

While the example shows an L-C check, a C-H check can be realized. In some examples, after the checker has validated the configuration the spine proxies can be checked to determine the correct next hop.

At sequence **1040**, one or more events can be generated. For example, when the validations are consistent (e.g., consistent with expectations of the validation) the application can generate an information event. In other examples, when one or more of the validations are not consistent (e.g., inconsistent with expectations of the validation), configurations are not on the correct leafs (according the L_Model) or when there are missing or extra information the application can generate an error event. The severity of the error event can at least be determined based on which validation is inconsistent and which device had the inconsistency (e.g., production device, test device, access point, border leaf, etc.).

The above VRF container check of BD deployment is an example of an application of a generic VRF container integrity check. When the VRF container is created, it can be populated with the L_Model, Li_Model, Ci_Model and/or Hi_Model that contain data relevant to/required by the check. Checker **620** can confirm the presence or absence of these models. By way of non-limiting examples, an appropriate Li_Model being present but a corresponding required Ci_Model not being present, would indicate an error in deployment. A Ci_Model being present but a required corresponding Li_Model not being present, would indicate improper extra information. An Li_Model or Ci_Model being present from another VRF, would also indicate improper extra information.

Security Contract Between Logical Groups

In some cases, there can be a security contract between endpoint groups (as illustrated below). In these cases the leafs will get the leaked subnets (and other information). Appliance **300** can perform an L-C check to determine if the RIB is properly programed. For example, as illustrated in FIG. **12**, when Contract **2** is configured, the RIB on Leaf **1** will include subnets 100.* and 200.* (e.g., from BD**1**) and subnets of BD**2** (e.g., 300.*, 400.*) leaked from Contract **2**. Also, Leaf **3** will include subnets 300.* and 400.* (from BD**2**) and subnets for BD**1** (e.g., 100.* and 200.*) leaked from Contract **2**. Without Contract **2** in place, Leaf **1** will not include BD**2** subnets and Leaf **3** will however include BD**1** subnets because of Contract **1**.

Logical Groups (e.g., EPGs) cannot be properly deployed if there is a clash between two or more Logical Groups. For example, if Logical Groups are using same interface, subnets, encap VLANs etc. In one example, as shown in FIG. **7**, Logical Group **1** (LG**1**) and Logical Group **2** (LG**2**) are initially independent from each other and do not clash. However, when Security Contract **750** is implemented, a clash between LG**1** and LG**2** subnets is possible. Subsequent a security contract being formed, the Logical Groups can be deployed on the leaf that hosts the Logical Groups (e.g., endpoints within the logical groups can communicate). After a security is formed between Logical Groups, the Logical Groups can be deployed on the leafs that host the Logical Groups and the leafs that host a Logical Group which is an endpoint to the contract (e.g., endpoints between logical groups that have a contract can communication). This enables the end points in the different Logical Groups to communicate with one another. For example, LG**1** is on Leaf **1** and LG**2** is on Leaf **2**. After a security contract is formed between LG**1** and LG**2**, LG**1** subnets will be deployed on Leaf **2** and LG**2** subnets will be deployed on Leaf **1**. However, the communication between Logical Groups that have a contract can also share prefixes (e.g., routes) between the leafs, which can result in a conflict because of the existence of a common prefix between the logical groups; when the configurations of LG**1** and LG**2** would clash (e.g., same subnet), the deployment might fail and an event generated.

In some examples, the contract can be between Logical Groups that reside in different VRFs. In this situation, internal routing leaking can be performed between the VRFs, and the checks can be in Layer 3, discussed below.

FIG. **12** illustrates a graphical view of a tenant configuration **1200** of a network environment (e.g., Fabric **120**). Tenant configuration **1200** can illustrate two BDs (e.g., BD**1** and BD**2**) bound to the same VRF (e.g., VRF**1**). Each BD can have one or more assigned subnets. For example, BD**1** can have assigned subnets 100.* and 200.*, and BD**2** can have assigned subnets 300.*. One or more Logical Groups (e.g., EPGs) can be bound to the one or more BDs. For example, EPG**1** and EPG**2** can be bound to BD**1** and EPG **3** can be bound to BD**2**. Each EPG can have one or more assigned subnets as well. For example, EPG**3** has assigned subnet 400.*. Each EPG can point to one or more Leafs. For example, EPG**1** can point to Leaf **1** and Leaf **2**, EPG**2** can point to Leaf **2** and EPG**3** can point to Leaf **3**.

In the above tenant configuration (e.g., **1200**), the endpoints within an EPG can communicate with one another, however, endpoints of one EPG cannot communication with endpoints of a different EPG without a security contract. For example, endpoints of EPG**3** cannot communication with endpoints of EPG**2** without first having a security contract (e.g., Contract **1**). When contract is in place between EPGs, endpoints of the EPGs subject to the contract can communicate. For example, when Contract **1** is in place, the endpoints in EPG**3** and EPG**2** can communicate.

When a security contract exists, the configurations (and subnets) will be deployed in the respectively connected Leafs. For example, when Contract **1** is in place, EPG**2** subnets will be deployed on Leaf **3** and EPG**3** subnets will be deployed on Leaf **2**. As such, the subnets of BD**1** (e.g., 100.* and 200.*) will be deployed on Leaf **3** and the subnets of BD**2** (e.g., 300.*) and EPG**3** (e.g., 400.*) will be deployed on Leaf **2**.

When subnets are deployed on leafs, Appliance **300** can verify the subnets are properly deployed, for example, by looking at resulting configuration created by the security contracts as an L-C check. The subnets can be verified by the security contracts and can create a VRF container (e.g., **1250**), as previously discussed. VRF container **1250**, can include the Li_Model configurations including the configurations created by security contracts. For example, Leaf **1-3** can all include subnets 100.*, 200.* and 300.*. Subnet 300.* is accessible by Leaf **1** and **2** based on Contract **1** and subnet 300.* is a BD subnet. Leaf **2** and **3** can both have subnet 400.* accessible based on Contract **1**. The Li_Model configuration can then be mapped to a Ci_Model configuration via the L-C check to determine consistency across the fabric.

Next Hop Check

Next, the application can determine if the next hops are proper. For example, each BD and EPG subnet should point to a spine proxy and the gateway IP should point to local. In some examples, route table **1275** can show the next hops for IP address and masks (e.g., using Longest Prefix Match). When an IP address of 100.0.0.1 comes in, the next hop will be Next Hop **1** because the full IP address is used (e.g., 32 bit mask in IPv4). When an IP address of 100.0.0.0/24 comes in, the next hop will be Next Hop **2** because mask of 28 (also shown as a *). This check can be a consistency check at the Ci_Model for the noted content.

RIB to FIB Equivalence

Appliance **300** can also determine that the RIB and FIB of a particular Leaf **104** or Spine **102** are consistent. The Routing Information Base (RIB) is contained within the LPM table of the Ci_Model of the particular Leaf **104** or Spine **102**. The Forwarding Information Base (FIB) is contained within the LPM table of the Hi_Model of the particular Leaf **104** or Spine **102**. The RIB to FIB check is a C-H check as described above on at least the overlapping fields of content that are specific to RIB and FIB operability.

As illustrated in FIG. **13**, device **1300** (e.g., Leaf **104**, Spine **102**, etc.) can include Line Card Controller **1310**, where the FIB resides and SUP Controller **1320**, where the RIB resides. The routing protocols works on the SUP level (software level). The RIB is compiled to the Line Card Controller, which physically programs to the hardware of the device. Appliance **300** can determine the equivalence by extracting the FIB and RIB and convert them to a common format, as illustrated by table **1330**. Table **1330** can show an IP address (e.g., 100.0.0.0), a mask (e.g., 32) and one or more next hops (e.g., NH**1**, NH**2**, etc.). Table **1330** can also include a "catch all" (e.g., *→DROP). For example, when an IP address is received that does not match an IP address/mask, the catch all will drop the packets. The entries can be compared to determine there are no inconsistencies between the next hops.

FIG. **14** illustrates an example flowchart for an example network assurance of a RIB-FIB equivalence of a network environment. The method shown in FIG. **14** is provided by way of example, as there are a variety of ways to carry out the method. Additionally, while the example method is illustrated with a particular order of sequences, those of ordinary skill in the art will appreciate that FIG. **14** and the sequences shown therein can be executed in any order that accomplishes the technical advantages of the present disclosure and can include fewer or more sequences than illustrated.

Each sequence shown in FIG. **14** represents one or more processes, methods or subroutines, carried out in the example method. The sequences shown in FIG. **14** can be implemented in a network environment such as network environment **100** shown in FIG. **1**A and **1**B. The application can be present on Appliance **300** and/or Checker **620**, although the application is not so limited.

Method **1400** can begin at sequence **1410**. At sequence **1410**, an application (e.g., Appliance **300**) can extract a RIB from the SUP Controller of a device (e.g., Leaf **104**, Spine **102**, etc.). At sequence **1420**, the application can extract a FIB from the Line Card Controller of the device. Both sequences **1410** and **1420** can entail polling one or more Leaf **104** or Spine **102** for the content, or in other examples obtaining the content from the received Ci_Model **624** and Hi_Model for one or more Leaf **104** or Spine **102**.

At sequence **1430**, the application can convert the extracted FIB and RIB to a common format (e.g., one of the FIB or RIB is converted into the format of the other, or both are converted to the same new format). At sequence **1440**, the application can create a union of the converted RIB and FIB (e.g., a set union including lists all RIBs and FIBs without duplication), such as illustrated by Table **1330**. Although shown as a collective table, the lists may be in distinct tables.

At sequence **1450**, the application can identify a first entry in the RIB and determine if there is a matching IP address/mask in the FIB with a matching next hop. If such a match exists, then control passes to sequence **1470** to see if there is a next entry to consider. If so, control passes back to sequence **1450** to check the next entry (e.g., the next entry in the RIB, and then turning to the entries in the FIBs).

For example with respect to Table **1330**, the first entry RIB **1**) has an IP address/mask 100.0.0.0/32 with a next hop of NH**1**. The same IP address/mask 100.0.0.0/32 with a next hop of NH**1** is found in the FIB, at FIB **1**). Since the RIB and FIB entries match, method **1400** can proceed to the next entry sequence **1470**. If there was no next entry then method **1400** can end. In this example there is a next entry of RIB **2**), and thus control passes to sequence **1450** for the checking of the next entry of RIB **2**).

At sequence **1450**, if the application does not identify a matching FIB entry for the RIB entry under inspection, then control passes sequence **1460**. At sequence **1460**, the application can determine if the mismatch is covered by another prefix, for example, via Longest Prefix Match. When there is not another prefix and/or if the next hop does not match, an error can be generated at **1480**.

For example with respect to Table **1330**, the entry RIB **2**) 100.0.0.1/32 does not have a matching FIB, and thus control passes to sequence **1460** to identify another covering prefix, which in this case exists as FIB **2**) 100.0.0.*/30. If the next hops matched (between RIB **2** and FIB **2**) control would pass to sequence **1450** for the next RIB entry. However, the next hops of RIB **2**) and FIB **2**) do not match (NH**1** v. NH**2**) and the error is noted at sequence **1480** before control returns to sequence **1470** consider the next entry.

In some cases, the mismatch can be a non-entry in one of the tables. For example, FIB **3**) 200.0.0.0/30 does not have a match in the RIB table, except the "catch all" (e.g., *→Drop). Any incoming IP address 200.0.0.0 will be dropped, even though the FIB table says route to NH**1**. In response to this type of mismatch, an error can be generated.

In some cases, there can be entries in a RIB or FIB that will not be used. For example, RIB **5**) will never be used since combined RIB **1**) to RIB **4**) cover all IPs in RIB **5**).

When all RIB s are examined, the process continues for the list of FIB s, and particularly those FIBs that were not accounted for by the initial RIB check. The process could also be reversed, in that the list of FIBs could be checked before RIBs. Or the system could switch between lists. The application is not limited to the manner in which the list of RIBs and FIBs is processed.

Validation of L3out (Internal-External Forwarding)

As shown above in FIG. **7**, internal subnets (e.g., 100.2.*) can be leaked to external networks (e.g., Network Device **114**) and external networks (e.g., 175.*) can be leaked to the Fabric. In order for communication to properly occur between the public subnets in the Fabric **120** and the external devices, Layer 3 out ("L3out") must be properly configured. Appliance **300** can determine that the L3out is properly configured.

The L3out interfaces model can include, at a minimum, leaf (e.g., border), port and network (e.g., 40.1.2.*). Border leafs can have L3out configured to access an outside device/network (e.g., Network Device **114**). To deploy an L3out interface the leaf, port and network can be configured. For example, an operator can program Leaf N, port eth1/10 and network 40.1.2.* into L_Model **270**A, for which in a manner discussed above Leaf N generates the corresponding CN_Model and HN_Model. Once configured, the link between Leaf N and Network Device **114** is important in transferring data external the fabric. In this case, network 40.1.2.* would own the link. The 100.2.* subnet (as shown in LPM Table **748**) can be leaked to Network Device **114** (through L3out interface and link 40.1.2.*). The subnet is leaked through routing protocols, such as, BGP, OSPF, EIGRP, etc. For example, in the routing protocols there are two peers: peer**1** is the border leaf (e.g., Leaf N) and peer**2** is the external device (e.g., Network Device **114**). The two peers will exchange their routes with each other. For example, peerl can tell peer**2** that it has public networks (e.g., 100.2.*) to leak outside the fabric and peer **2** can tell peer**1** that it has external routes (e.g., 175.*) to be leaked inside the fabric.

L3out loopback is an interface for configuring networking protocols (e.g., BGP). Static routes can be programmed by the Fabric **120**. For example, Network Device **114** can have network 200.* that has not been leaked to the Fabric **120**. In these cases, the L_Model can directly program the 200.* network for communicating with an external router (e.g., Network Device **114**). EPG (Instp) can be used to control import of external routes. For example, Network Device **114** can have several routes (e.g., 100.*, 300.*, 400.*, etc.) leaked to Fabric **120**. These networks can be tagged with EPGs. For example, 100.* can be tagged with EPG**1** (e.g., Logical Group **1**), 300.* can be tagged with EPG**2** (e.g., Logical Group **2**) and 400.* can be tagged with EPG**3** (e.g., Logical Group **3**). As such, whenever an incoming packet comes into Fabric **120** from these networks, the packet will be tagged with the associated EPG.

Appliance **300** can perform checks on the L3out through an L-C Model check. For example, Appliance **300** can verify the interface, loopback, and static routes are programmed on the border leafs (e.g., present in the LPM Table). Appliance **300** can also verify one or more EPGs of L3out are correct. Appliance **300** can verify, for each network, the next hop is proper.

FIG. **15** illustrates an example flowchart for an example network assurance of L3out configuration of a network environment. The method shown in FIG. **15** is provided by way of example, as there are a variety of ways to carry out the method. Additionally, while the example method is illustrated with a particular order of sequences, those of ordinary skill in the art will appreciate that FIG. **15** and the sequences shown therein can be executed in any order that accomplishes the technical advantages of the present disclosure and can include fewer or more sequences than illustrated.

Each sequence shown in FIG. **15** represents one or more processes, methods or subroutines, carried out in the example method. The sequences shown in FIG. **15** can be implemented in a network environment such as network environment **700** shown in FIG. **7**. The application can be present on Appliance **300** and/or Checker **620**, although the application is not so limited.

Method **1500** can begin at sequence **1510**. At sequence **1510** the various models (e.g., L_Model, C_Model, and/or H_Model) to be checked are received. For example, one or more Leafs **104**, Spines **102** and Controllers **116** in Fabric **120** can send to the application (e.g., Assurance Appliance **300**) L_Model **270**A/B, Ci_Model **274**, and Ci_Model **276**. Those received models can include information content that can be subject to the validation process. In some examples, the information relevant to an L3out assurance check can include interface (e.g., leaf, port, network), loopback (e.g., protocol), static routes, and EPG.

At sequence **1520**, the application can validate networks configured to communicate through L3out are in the LPM Table (e.g., L3 Table). The LPM Table (e.g., C_Model) can contain configuration of the devices in the network (e.g., Leafs **104**, Spines **102**, etc.). The L_Models and C_Models can be converted to a common format as discussed above, and the relevant content of overlapping fields can be compared. For example, the L3out interface assurance considers the fields of leaf, port and network. Appliance **300** can validate that the leaf from the configuration has the port and network deployed as shown in the configuration (e.g., L_Model). Appliance **300** can perform similar validation for the loopback (consideration of fields of leaf and network) and static routes (consideration of the fields of leaf, network and next hop). EPG can be validated by the application as well via an L-C check.

At sequence **1530**, the application can validate the next hops via C_Model consistency check. For example, validating the LPM Tables at each leaf includes next hop entries to communicate with the border leaf (e.g., for external communication). As shown in FIG. **7**, Leaf **2** can include an LPM Table **742**. LPM Table **742** can include subnets and next hops. As previously discussed, subnet 100.2.* has been leaked from Leaf N to Network Device **114** and when Leaf **2** wants to communication with the external network, data is routed through Leaf N (or another border leaf connected to Network Device **114**). Appliance **300** can validate the next hop routes in the LPM tables of the leafs and spines are correct.

At sequence **1540**, one or more events can be generated. For example, when the validations are consistent (e.g., consistent with expectations of the validation) the application can generate an informational event. In other examples, when one or more of the validations are not consistent (e.g., inconsistent with expectations of the validation), configurations are not on the correct leafs (according the L_Model) or when there are missing or extra information the application can generate an error event. The severity of the error event can at least be determined based on which validation is inconsistent and which device had the inconsistency (e.g., production device, test device, access point, border leaf, etc.).

Validation of BD-L3out Configuration (Internal-External Forwarding)

BD-L3out association enables internal networks to be leaked external to the fabric, that is, the external router should know about internal networks and where data should be routed for accessing the internal networks (e.g., internal Fabric **120**). As shown in FIG. **7**, Leaf **2** has a public network 100.2.*. For network 100.2.* to be accessed from outside the fabric (e.g., by network device **114**), the BD-L3out association can be configured. As shown in FIG. **16**, the BD-L3out association can include, BD subnet is marked public (e.g., 100.2.*), BD is associated with L3out (e.g., 1650) and a security contract exists between the EPG of BD and EPG of L3out (e.g., Contract **1**). When BD subnet is marked public and BD is associated with L3out, routing can work properly external to the fabric.

Appliance **300** can validate these BD-L3out configuration conditions. In particular, Appliance **300** can confirm that the models reflect that the internal networks have in fact been leaked. This specific check uses a series of L_Model consistency checks (or a single check that considers multiple fields of information).

FIG. **17** illustrates an example flowchart for an example network assurance of BD-L3out association configuration of a network environment. The method shown in FIG. **17** is provided by way of example, as there are a variety of ways to carry out the method. Additionally, while the example method is illustrated with a particular order of sequences, those of ordinary skill in the art will appreciate that FIG. **17** and the sequences shown therein can be executed in any order that accomplishes the technical advantages of the present disclosure and can include fewer or more sequences than illustrated.

Each sequence shown in FIG. **17** represents one or more processes, methods or subroutines, carried out in the example method. The sequences shown in FIG. **17** can be implemented in a network environment such as network environment **700** shown in FIG. **7** and network diagram

1600 shown in FIG. **16**. The application can be present on Appliance **300** and/or Checker **620**, although the application is not so limited.

At sequence **1710** the various models (e.g., L_Model, C_Model, and/or H_Model) to be checked are received. For example, each Controller **116** in the Fabric **120** can send to the application (e.g., Assurance Appliance **300** and/or Checker **620**) one or more L_Models **270**A/B, and one or more Leafs **104** and Spines **102** can send corresponding Ci_Model **274**, and Ci_Model **276**. In another example, some but not all of the L_Model, C_Model, and/or H_Model configurations are provided and/or received. Those received models can include information content, at least some of which will be subject to the validation process. In some examples, the information can include L3out configuration data and BD configuration data.

At sequence **1720**, the application via an L_Model consistency check identifies whether any BD subnets are marked public. In some examples, BD subnets in the fabric are configured to be private, shared, etc. In order to be marked public, the operator must specify the subnet as public in L_Model **270**A and push the configuration to the Controller **116**. The application can verify via an L-Model consistency check whether any BD subnet in the received L_Model **622** is marked public. If not, then this check ends at sequence **1760**. If one or more of the BD subnets in the received L_Model **622** are marked as public, then the process continues at **1730** for each subnet identified as public; the process will be described with respect to a single subnet so identified, although it is to be understood that the process would also apply to multiple identified subnets.

At sequence **1730**, the application via an L_Model consistency check can validate the public BD is associated with an L3out. The BD is associated with L3out through the BD configuration. The BD configuration can be programmed by the operator in L_Model **270**A at the Controller **116** (e.g., Tenant Configuration **740**), and which can subsequently arrive at checker **620** via sequence **1710** above. An example of a BD-L3out association **1650** is shown in FIG. **16**. The application can verify the association via an L-Model consistency check.

At sequence **1740**, the application via an L_Model consistency check can validate a contract between the EPGs (e.g., Logical Groups). As shown above, the L3out can have an EPG (e.g., EPG**2**) and BD can have an EPG (e.g., EPG**1**). When a contract (e.g., Contract **1**) has been formed between the EPGs, the associated endpoints can then communicate. Appliance **300** can validate that a security contract is present between the EPG under L3out and the EPG under BD.

At sequence **1750**, one or more events can be generated. For example, when the validations are consistent (e.g., consistent with expectations of the validation) the application can generate an information event. In other examples, when one or more of the validations are not consistent (e.g., inconsistent with expectations of the validation), configurations are not on the correct leafs (according the L_Model) or when there is missing or extra information the application can generate an error event. The severity of the error event can at least be determined based on which validation is inconsistent and which device had the inconsistency (e.g., production device, test device, access point, border leaf, etc.).

Proper Propagated Learned (Imported) Routes

Learned Routes (e.g., imported routes) are external networks that are leaked (i.e., imported) inside the Fabric **120**. The external networks (e.g., to be leaked) can be networks that an external device (e.g., Network Device **114**) wants to share with the Fabric **120** via a border leaf (e.g., Leaf N). The Fabric **120** can in theory import all networks provided by the external router or only specific external networks. The decisions can be based on resources of the network devices, for example the LPM table. When all external routes are imported, for example thousands of networks, expensive resources are utilized by storing these learned routes at each network device (e.g., Leafs **104**, Spines **102**, etc.). The learned routes populate the LPM Tables stored in the TCAM of each network device. Overpopulating these resources can affect the efficiency and overall operation of the fabric. The border leaf (e.g., Leaf N) can decide (e.g., based on operator intent) which external networks to import.

The deployment of the instruction to permit a leak of a particular external network is programmed by the operator into the L_Model **270**A, and can identify for a particular border Leaf **104** (e.g., Leaf N) what network(s) can be leak into Fabric **120**. The particular border Leaf **104** (e.g., Leaf N) can store the permissible network(s) in EPGs defined in the L3out table (e.g., table **1806** for Leaf N) within the Ci_Model **274**.

When an external device (e.g., Network Device **114**) wants to share an external network with the Fabric **102** via a border leaf (e.g., Leaf N), the border leaf (e.g., Leaf N) initially determines from its L3out table whether import of that network is permissible. If permissible, the border leaf (e.g., Leaf N) sets that external device as the next hop in the LPM table (e.g., **748** for Leaf N). The L3out of the border Leaf (e.g., Leaf N) is under a particular VRF, and as the "source" of the leak the border Leaf propagates (e.g., leaks) that learned route to other Leafs **104** (e.g., student leafs) which have an L3out or BD that is under that same particular VRF. Those "student" Leafs **104** will store the learned route in their LPM table (e.g., **1802** for Leaf **1** and **742** for Leaf **2**) and set the next hop to the source Leaf (e.g. Leaf N). By virtue of the source Leaf and the student Leaf having L3out and/or BD under the same VRF, these source and student Leafs **104** define a "VRF Leaf Group."

Non-limiting examples of learned routes are illustrated in Fabric **120** of FIG. **7**. L_Model **270**A/B contains instructions for Leaf N that it can import from external network 175.*. Leaf N includes this in its CN model **272** as an L3out in LPM table **1806**. An external Network Device **114** wants to export networks to Fabric **120** through Border Leaf N, for example, external subnets 175.*, 185.*, 195.* as listed in routing and forwarding table **744** of Network Device **114**. Border Leaf N can import network 175.* (e.g., EPG (175.*) because it is listed in table **1806**, but cannot import networks 185.* and 195.* because they are not present in table **1806**. Border Leaf N updates table **748** along with the next hop indictor of network device **114** (175.*→Device **114**). Border Leaf N can then spreads the leak to the remainder of the VRF Leaf Group, which in this case includes Leaf **1** and Leaf **2**. Leaf **1** and Leaf **2** can update their LPM table (e.g., **1802**, **742**) at the Ci_Model **274** level to reflect the import of 175.* and set Leaf N as the corresponding next hop to reflect it is the source Leaf (e.g., 175.*→Leaf N).

In some examples, multiple border Leafs import a network from the same external device. In FIG. **7**, Leaf **3** is also a border leaf as shown by dashed line **1804** to external Network Device **114**, and as such also imports network 175.* and propagates the imported networks to Leafs **1** and **2**. The LPM tables (e.g., **1802**, **742**) reflect that the next hop can be either Leaf **3** or Leaf N (e.g., 175.*→Leaf **3**, N).

In some examples, the LPM tables may have errors. For example, the LPM Table of the devices (e.g., **1802**, **742**, etc.) can include equivalent learned routes as the LPM Table of the border leaf (e.g., **748**). Turning to FIG. **7**, the LPM Table of Leaf **2** (e.g., **742**) shows an equivalent learned route (e.g., 175.*) as in Border Leaf N, while the LPM Table of Leaf **1** (e.g., **1802**) shows an extra learned route (e.g., 185.*) not in border Leaf N. Network 185.* was not authorized for importation by L_Model **270**A. The presence of learned route 185.* is thus a discrepancy and can generate an error.

FIG. **18** illustrates an example flowchart for an example network assurance of learned routes of a network environment. The method shown in FIG. **18** is provided by way of example, as there are a variety of ways to carry out the method. Additionally, while the example method is illustrated with a particular order of sequences, those of ordinary skill in the art will appreciate that FIG. **18** and the sequences shown therein can be executed in any order that accomplishes the technical advantages of the present disclosure and can include fewer or more sequences than illustrated.

Each sequence shown in FIG. **18** represents one or more processes, methods or subroutines, carried out in the example method. The sequences shown in FIG. **18** can be implemented in a network environment such as network environment **700** shown in FIG. **7**. The application can be present on Appliance **300** and/or Checker **620**, although the application is not so limited.

Method **1800** can begin at sequence **1810**. At sequence **1810**, an application (e.g., Assurance Appliance **300**) can receive various models (e.g., L_Model, C_Model, and/or H_Model) to be checked. For example, each Controller **116** in the Fabric **120** can send to the application (e.g., Assurance Appliance **300** and/or Checker **620**) one or more L_Models **270**A/B, and each Leaf **104** and Spine **102** sends its corresponding Ci_Model **274**, and Ci_Model **276**. In another example, some but not all of the L_Model, C_Model, and/or H_Model configurations are provided and/or received. Those received models will include information content, at least some of which will be subject to the validation process. For example, each border leaf (e.g., Leaf **3**, Leaf N, etc.) in the Fabric **120** can send to the application, information associated with software model (C_Model). In some examples, the information can be the LPM Table (e.g., L3 Table) and L3out configuration.

Learned routes can be present in the LPM Table within the Ci_Model **274** of border nodes (e.g., border Leaf) and the EPG of L3out in the L_Model **270**A. At sequence **1820**, the application examines the Ci_Model **624** for one or more border Leafs along with the L_Model **622** to confirm that the learned routes are consistent with each other. For example, when the EPG of L3out includes the imported route 175.*, the LPM Table should include 175.* as an imported route (and no other learned routes, unless imported from a different border leaf or a different L3out). In response to discrepancies of the learned routes between EPG of L3out and the LPM Table an error event can be generated (e.g., at sequence **1860**). In response to no discrepancies, an informational event can be generated.

Sequence **1820** may require a common format step for Ci_Model **624** and L_Model **622**, although the subject matter of interest may be extract from overlapping fields of the models the common format as well as from fields in the models that do not overlap.

At sequence **1830**, the application can validate the learned routes are present on the "source" are "student" leafs (e.g., where the VRF for the EPG/Logical Groups are present). The application thus checks the Ci_Model **624** configuration for all of Leafs within a common VRF Leaf Group to confirm that the learned routes are consistent across the group. This is can be a C-Model level consistency check per Ci_Model and across multiple Ci_Models. With respect to FIG. **7**, this check would confirm that all listings of 175.* are proper in those Leafs; it would also identify that network 185.* is improperly listed in **1802** and trigger a corresponding error event.

At sequence **1840**, the application can validate the next hops for the imported routes. For a learned route in a source Leaf, this is a Ci_Model level consistency check to validate that the next hop is directed to the external device. By way of non-limiting example, in FIG. **7** the CN_Model for Leaf N is checked to confirm that the next hop for network **175** is the external device that requested import (e.g., 175.*→Device **114**). In the example of a learned route in a student leaf, this is a Ci_Model level consistency check to validate that the next hop is directed to the source Leaf(s). By way of non-limiting example, in FIG. **7** the Ci_Model for Leafs **1** and **2** are checked to confirm that the learned routes (e.g., 175.*) are directed to the border leafs (e.g., Leaf **3** and N). When there is more than one border leaf and two next hops (e.g., 175, e.g., 175.*→Leaf **3**, N) the application can validate both next hops (for network redundancy this is common).

When routing between two next hops, the leaf (e.g., Leaf **1**) can compute a hash based on flow (e.g., source IP, source port, destination IP, destination port, etc.). The computed hash will be modulo with the number of border leafs. In this example, there are two border leafs so the computed hash modulo **2** (e.g., hash % 2). The routing would then be sprayed among the modulo output.

At sequence **1850**, one or more events can be generated. For example, when the validations are consistent (e.g., consistent with expectations of the validation) the application can generate an information event. In other examples, when one or more of the validations are not consistent (e.g., inconsistent with expectations of the validation), configurations are not on the correct leafs (according the L_Model) or when there are missing or extra information the application can generate an error event. The severity of the error event can at least be determined based on which validation is inconsistent and which device had the inconsistency (e.g., production device, test device, access point, border leaf, etc.).

Detection of Overlapping Subnets

An overlapping subnet in a network (e.g., Fabric **120**) can cause misrouting and lost packets during forwarding (e.g., using LPM). In a fabric there can be multiple networks in each VRF, for example, BD subnets; EPG subnets (function same as BD subnets); L3out interface; L3out loopback; L3out static routes; L3out loopbacks; learned routes; etc. These multiple networks can be determined by operator intent or imported (e.g., learned). Each of the networks (e.g., subnets) can have an IP address and a mask (e.g., IPv4, IPv6, etc.). The mask determines how much of the IP address is used in forwarding data (e.g., LPM). For example, an IP/mask of 200.1.1.1/16 would be used as 200.1.* because the last 16 bits (in an IPv4 address) are masked.

FIG. **19** illustrates network diagram **1900** of potential subnet overlaps and exceptions. Generally, subnets in a fabric can be spread out across the possible subnets. However, operator intent (e.g., misintent) and masks can create unintended overlap. For example, BD**1** subnets and BD**2** subnets can overlap in that BD**1** and BD**2** can be configured with at least one identical subnets (e.g., both are configured with a subnet of 100.1.1.1). In this example, there is an overlap and an event is generated. In other examples, this overlap can be constrained by the mask. For example, BD**1** can have a mask of 32 (e.g., 100.1.1.1/32) and BD**2** can have a mask of 24 (e.g., 100.1.1.1/24). In this example, when forwarding data BD**1** would have subnet 100.1.1.1 and BD**2** would have subnet 100.1.1.*. As such, anything other than 100.1.1.1 would be forwarded to BD**2**.

While the above overlap is constrained by the mask, a complete overlap is still possible as shown by BD**3** subnets and BD**4** subnets. For example, BD**3** subnets can include 200.1.1.0/16 and BD**4** subnets can include 200.1.1.1/24. In this example, while the subnets are different, the mask would overlap them, BD**3** subnet would be 200.1.* and BD**4** subnet would be 200.1.1.*. As such, any forwarding to 200.1.1.0 (or 200.1.1.*) would go to BD**4** subnet even though the intent could be to send to BD**3** subnet (because LPM). This overlapping would generate an event. One exception to this would be if BD**3** and BD**4** were the same BD (e.g., forwarding would be to the same BD so no clash).

In some situations, the EPGs to which there is a security contract can be in different VRFs, as shown in FIG. **12** (e.g., dashed line from BD**2** to VRF**2**). For example, BD**2** can be bound to VRF**2** and BD**1** can be bound to VRF**1**. When Security Contract **2** is formed between EPG**3** (bound to BD**2**) and EPG**1** (bound to BD**1**) the subnets from BD**2** (e.g., 300.* and 400.*) are leaked to VRF**1** and the subnets from BD**1** (e.g., 100.* and 200.*) are leaked to VRF**2**. Once, the subnets are leaked, VRF**1** cannot use subnets 300.* and 400.* independently and VRF**2** cannot use subnets 100.* and 200.* independently without their being a clash of subnets. Appliance **300** is configured to verify and check there are no clashes between subnets when contracts are formed between EPGs.

There are some exceptions to the overlapping which are shown by the Learned Routes and BD**5** subnets. In this example, the Learned Routes can have a subnet of 200.* (e.g., mask 8) and BD**5** subnet can have a subnet of 200.1.1.*. The BD**5** subnet is owned by the fabric (e.g., internal) and the Learned Routes is owned external. In this example, the overlap does not matter as when using LPM because anything with a 200.1.1.XXX will be forwarded to BD**5**, and everything else will be forwarded external. As such, internal routing is given preference over external and there will be no misrouting of data. However, when the situations are reversed (BD**5** subnet being 200.* and external being 200.1.1.*), the internal network is not provided preference and internal data could be sent outside the fabric, and an error can be generated.

FIG. **20** illustrates an example flowchart for an example network assurance of learned routes of a network environment. The method shown in FIG. **20** is provided by way of example, as there are a variety of ways to carry out the method. Additionally, while the example method is illustrated with a particular order of sequences, those of ordinary skill in the art will appreciate that FIG. **20** and the sequences shown therein can be executed in any order that accomplishes the technical advantages of the present disclosure and can include fewer or more sequences than illustrated.

Each sequence shown in FIG. **20** represents one or more processes, methods or subroutines, carried out in the example method. The sequences shown in FIG. **20** can be implemented in a network environment such as network environment **700** shown in FIG. **7** and network diagram **1900** shown in FIG. **19**. The application can be present on Appliance **300** and/or Checker **620**, although the application is not so limited.

Method **2000** can begin at sequence **2010**. At sequence **2010** an application (e.g., Assurance Appliance **300**) receives various models (e.g., L_Model, C_Model, and/or H_Model) to be checked. For example, one or more Controllers **116** in the Fabric **120** can send to the application (e.g., Assurance Appliance **300** and/or Checker **620**) one or more L_Models **270**A/B, and one or more Leafs **104** and Spines **102** can send corresponding Ci_Model **274**, and Ci_Model **276**. In another example, some but not all of the L_Model, C_Model, and/or H_Model configurations are provided and/or received. Those received models will include information content, at least some of which will be subject to the validation process. In some examples, the information can include the multiple networks in each VRF (e.g., from the LPM table, tenant config, etc.).

At sequence **2020**, the application can determine impermissible overlap between the received networks for each VRF (e.g., in the L_Models received). Subnets can be found in the L_Model **270**A/B, and learned routes can be found in individual Ci_Model **274** configuration for each VRF. All of these subnets, including learned routes, can be examined to direct an overlap. An overlap for which no exception exists constitutes a discrepancy.

At sequence **2030**, one or more events can be generated. For example, when the validations are consistent (e.g., consistent with expectations of the validation) the application can generate an information event. In other examples, when one or more of the validations are not consistent (e.g., inconsistent with expectations of the validation), configurations are not on the correct leafs (according the L_Model) or when there are missing or extra information the application can generate an error event. The severity of the error event can at least be determined based on which validation is inconsistent and which device had the inconsistency (e.g., production device, test device, access point, border leaf, etc.).

The foregoing embodiments have been described with reference to a Leaf/Spine topology. However, the application is not so limited, and the methodologies can be applied to other topologies.

The disclosure now turns to FIGS. **21** and **22**, which illustrate example network devices and computing devices, such as switches, routers, load balancers, client devices, and so forth.

FIG. **21** illustrates an example network device **2100** suitable for performing switching, routing, load balancing, and other networking operations. Network device **2100** includes a central processing unit (CPU) **2104**, interfaces **2102**, and a bus **2110** (e.g., a PCI bus). When acting under the control of appropriate software or firmware, the CPU **2104** is responsible for executing packet management, error detection, and/or routing functions. The CPU **2104** can accomplish all these functions under the control of software including an operating system and any appropriate applications software. CPU **2104** may include one or more processors **2108**, such as a processor from the INTEL X86 family of microprocessors. In some cases, processor **2108** can be specially designed hardware for controlling the operations of network device **2100**. In some cases, a memory **2106** (e.g., non-volatile RAM, ROM, etc.) also forms part of CPU **2104**. However, there are many different ways in which memory could be coupled to the system.

The interfaces **2102** are typically provided as modular interface cards (sometimes referred to as "line cards"). Generally, they control the sending and receiving of data packets over the network and sometimes support other peripherals used with the network device **2100**. Among the interfaces that may be provided are Ethernet interfaces, frame relay interfaces, cable interfaces, DSL interfaces, token ring interfaces, and the like. In addition, various very high-speed interfaces may be provided such as fast token ring interfaces, wireless interfaces, Ethernet interfaces, Gigabit Ethernet interfaces, ATM interfaces, HSSI interfaces, POS interfaces, FDDI interfaces, WIFI interfaces, 3G/4G/5G cellular interfaces, CAN BUS, LoRA, and the like. Generally, these interfaces may include ports appropriate for communication with the appropriate media. In some cases, they may also include an independent processor and, in some instances, volatile RAM. The independent processors may control such communications intensive tasks as packet switching, media control, signal processing, crypto processing, and management. By providing separate processors for the communications intensive tasks, these interfaces allow the master microprocessor **604** to efficiently perform routing computations, network diagnostics, security functions, etc.

Although the system shown in FIG. **21** is one specific network device of the present invention, it is by no means the only network device architecture on which the present invention can be implemented. For example, an architecture having a single processor that handles communications as well as routing computations, etc., is often used. Further, other types of interfaces and media could also be used with the network device **2100**.

Regardless of the network device's configuration, it may employ one or more memories or memory modules (including memory **2106**) configured to store program instructions for the general-purpose network operations and mechanisms for roaming, route optimization and routing functions described herein. The program instructions may control the operation of an operating system and/or one or more applications, for example. The memory or memories may also be configured to store tables such as mobility binding, registration, and association tables, etc. Memory **2106** could also hold various software containers and virtualized execution environments and data.

The network device **2100** can also include an application-specific integrated circuit (ASIC), which can be configured to perform routing and/or switching operations. The ASIC can communicate with other components in the network device **2100** via the bus **2110**, to exchange data and signals and coordinate various types of operations by the network device **2100**, such as routing, switching, and/or data storage operations, for example.

FIG. **22** illustrates a computing system architecture **2200** wherein the components of the system are in electrical communication with each other using a connection **2205**, such as a bus. Exemplary system **2200** includes a processing unit (CPU or processor) **2210** and a system connection **2205** that couples various system components including the system memory **2215**, such as read only memory (ROM) **2220** and random access memory (RAM) **2225**, to the processor **2210**. The system **2200** can include a cache of high-speed memory connected directly with, in close proximity to, or integrated as part of the processor **2210**. The system **2200** can copy data from the memory **2215** and/or the storage device **2230** to the cache **2212** for quick access by the processor **2210**. In this way, the cache can provide a performance boost that avoids processor **2210** delays while waiting for data. These and other modules can control or be configured to control the processor **2210** to perform various actions. Other system memory **2215** may be available for use as well. The memory **2215** can include multiple different types of memory with different performance characteristics. The processor **2210** can include any general purpose processor and a hardware or software service, such as service **1** **2232**, service **2** **2234**, and service **3** **2236** stored in storage device **2230**, configured to control the processor **2210** as well as a special-purpose processor where software instructions are incorporated into the actual processor design. The processor **2210** may be a completely self-contained computing system, containing multiple cores or processors, a bus, memory controller, cache, etc. A multi-core processor may be symmetric or asymmetric.

To enable user interaction with the computing device **2200**, an input device **2245** can represent any number of input mechanisms, such as a microphone for speech, a touch-sensitive screen for gesture or graphical input, keyboard, mouse, motion input, speech and so forth. An output device **2235** can also be one or more of a number of output mechanisms known to those of skill in the art. In some instances, multimodal systems can enable a user to provide multiple types of input to communicate with the computing device **2200**. The communications interface **2240** can generally govern and manage the user input and system output. There is no restriction on operating on any particular hardware arrangement and therefore the basic features here may easily be substituted for improved hardware or firmware arrangements as they are developed.

Storage device **2230** is a non-volatile memory and can be a hard disk or other types of computer readable media which can store data that are accessible by a computer, such as magnetic cassettes, flash memory cards, solid state memory devices, digital versatile disks, cartridges, random access memories (RAMs) **2225**, read only memory (ROM) **2220**, and hybrids thereof.

The storage device **2230** can include services **2232**, **2234**, **2236** for controlling the processor **2210**. Other hardware or software modules are contemplated. The storage device **2230** can be connected to the system connection **2205**. In one aspect, a hardware module that performs a particular function can include the software component stored in a computer-readable medium in connection with the necessary hardware components, such as the processor **2210**, connection **2205**, output device **2235**, and so forth, to carry out the function.

For clarity of explanation, in some instances the present technology may be presented as including individual functional sequences including functional sequences comprising devices, device components, steps or routines in a method embodied in software, or combinations of hardware and software.

In some embodiments the computer-readable storage devices, mediums, and memories can include a cable or wireless signal containing a bit stream and the like. However, when mentioned, non-transitory computer-readable storage media expressly exclude media such as energy, carrier signals, electromagnetic waves, and signals per se.

Methods according to the above-described examples can be implemented using computer-executable instructions that are stored or otherwise available from computer readable media. Such instructions can comprise, for example, instructions and data which cause or otherwise configure a general purpose computer, special purpose computer, or special purpose processing device to perform a certain function or group of functions. Portions of computer resources used can be accessible over a network. The computer executable instructions may be, for example, binaries, intermediate format instructions such as assembly language, firmware, or source code. Examples of computer-readable media that may be used to store instructions, information used, and/or information created during methods according to described examples include magnetic or optical disks, flash memory, USB devices provided with non-volatile memory, networked storage devices, and so on.

Devices implementing methods according to these disclosures can comprise hardware, firmware and/or software, and can take any of a variety of form factors. Typical examples of such form factors include laptops, smart phones, small form factor personal computers, personal digital assistants, rackmount devices, standalone devices, and so on. Functionality described herein also can be embodied in peripherals or add-in cards. Such functionality can also be implemented on a circuit board among different chips or different processes executing in a single device, by way of further example.

The instructions, media for conveying such instructions, computing resources for executing them, and other structures for supporting such computing resources are means for providing the functions described in these disclosures.

Although a variety of examples and other information was used to explain aspects within the scope of the appended claims, no limitation of the claims should be implied based on particular features or arrangements in such examples, as one of ordinary skill would be able to use these examples to derive a wide variety of implementations. Further and although some subject matter may have been described in language specific to examples of structural features and/or method steps, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to these described features or acts. For example, such functionality can be distributed differently or performed in components other than those identified herein. Rather, the described features and steps are disclosed as examples of components of systems and methods within the scope of the appended claims.

Claim language reciting "at least one of" refers to at least one of a set and indicates that one member of the set or multiple members of the set satisfy the claim. For example, claim language reciting "at least one of A and B" means A, B, or A and B.

What is claimed is:

1. A system for performing a network assurance check of proper deployment of a configuration in a fabric, comprising:

at least one memory configured to store data; and

at least one processor operable to execute instructions associated with the data, which when executed by the at least one processor, causes the processor to:

receive, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric, the global logical model including at least one virtual routing and forwarding instance (VRF);

receive, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices;

convert, for each network device, the global logical model into a local logical model in the first format, the local logical model being at least a portion of the received global logical model that is specific to operability of the corresponding each network device;

create a container for each VRF of the at least one VRF in the received global logical model;

populate each of the created containers with the local logical model and the software model for each of the network devices associated with the VRF; and

confirm bridge domain (BD) subnets in the populated containers match.

2. The system of claim **1**, wherein in the populated container a software model without a corresponding local logical model represents an improper extra item.

3. The system of claim **1**, wherein in the populated container a local logical model without a corresponding software model represents an error in deployment of the global logical model.

4. The system of claim **1**, wherein the population comprises a set union, such that the populated VRF container does not contain any duplicative BD subnets.

5. The system of claim **1**, further comprising instruction which when executed by the at least one processor, causes the at least one processor to:

subtract one of the software models from a corresponding local logical hardware model;

subtract the corresponding local logical model from the one of the software models;

wherein a mismatch between the subtractions represents a discrepancy.

6. The system of claim **5**, further comprising instructions, which when executed by the at least one processor, causes the at least one processor to generate an error event in response to a mismatch between the subtractions.

7. The system of claim **1**, further comprising instructions, which when executed by the at least one processor, causes the at least one processor to generate an error event in response to a mismatch in the bridge domain (BD) subnets in the populated container.

8. A method for performing a network assurance check of proper deployment of a configuration in a fabric, comprising:

receiving, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric, the global logical model including at least one virtual routing and forwarding instance (VRF);

receiving, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices;

converting, for each network device, the global model into a local logical model in the first format, the local logical model being at least a portion of the received global logical model that is specific to operability of the corresponding each network device;

creating a container for each VRF of the at least one VRF in the received global logical model;

populating each of the created VRF containers with the local logical model and the software model for each of the network devices associated with the VRF; and

confirming bridge domain (BD) subnets in the populated VRF container match.

9. The method of claim **8**, wherein in the populated container a software model without a corresponding local logical model represents an improper extra item.

10. The method of claim **8**, in the populated VRF container a local logical model without a corresponding software model represents an error in deployment of the global logical model.

11. The method of claim **8**, wherein the populating comprises a set union, such that the populated VRF container does not contain any duplicative BD subnets.

12. The method of claim **8**, wherein the method further comprises, in the container:

subtracting one of the software models from a corresponding local logical hardware model;

subtracting the corresponding local logical model from the one of the software models;

wherein a mismatch between the subtractions represents a discrepancy.

13. The method of claim **12**, further comprising generating an error event in response to a mismatch between the subtractions.

14. The method of claim **8**, further comprising generating an error event in response to a mismatch in the bridge domain (BD) subnets in the populated VRF.

15. At least one non-transitory computer readable medium storing instructions, which when executed by a processor causes the processor to:

receive, from a controller, a global logical model in a first format, the global logical model containing instructions on how endpoints connected to a network fabric communicate within the fabric, the global logical model including at least one virtual routing and forwarding instance (VRF);

receive, from one or more network devices within the fabric, a software model being at least a subset of instructions from the global logical model in a second format executable on the one or more network devices, the subset of instructions being instructions from the global logical model that are specific to operability of the one or more network devices;

convert, for each network device, the global model into a local logical model in the first format, the local logical model being at least a portion of the received global logical model that is specific to operability of the corresponding each network device;

create a container for each VRF of the at least one VRF in the received global logical model;

populate each of the created containers with the local logical model and the software model for each of the network devices associated with the VRF; and

confirm bridge domain (BD) subnets in the populated containers match.

16. The at least one non-transitory computer readable medium of claim **15**, wherein in the populated container a software model without a corresponding local logical model represents an improper extra item.

17. The at least one non-transitory computer readable medium of claim **15**, in the populated container a local logical model without a corresponding software model represents an error in deployment of the global logical model.

18. The at least one non-transitory computer readable medium of claim **15**, wherein the population comprises a set union, such that the populated VRF container does not contain any duplicative BD subnets.

19. The at least one non-transitory computer readable medium of claim **15**, further comprising instructions to, in the container:

subtract one of the software models from a corresponding local logical hardware model;

subtract the corresponding local logical model from the one of the software models,

wherein a mismatch between the subtractions represents a discrepancy.

20. The at least one non-transitory computer readable medium of claim **15**, further comprising instructions, which when executed by the at least one processor, causes the at least one processor to generate an error event in response to a mismatch in the bridge domain (BD) subnets in the populated container.

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