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A Data Model for Network Topologies
draft-ietf-i2rs-yang-network-topo-18.txt

Abstract

This document defines an abstract (generic) YANG data model for network/service topologies and inventories. The data model serves as a base model which is augmented with technology-specific details in other, more specific topology and inventory data models.

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Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

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Table of Contents

1.	Introduction	3
2.	Key Words	7
3.	Definitions and Acronyms	7
4.	Model Structure Details	8
4.1.	Base Network Model	8
4.2.	Base Network Topology Data Model	10
4.3.	Extending the data model	12
4.4.	Discussion and selected design decisions	12
4.4.1.	Container structure	12
4.4.2.	Underlay hierarchies and mappings	13
4.4.3.	Dealing with changes in underlay networks	13
4.4.4.	Use of groupings	14
4.4.5.	Cardinality and directionality of links	14
4.4.6.	Multihoming and link aggregation	15
4.4.7.	Mapping redundancy	15
4.4.8.	Typing	15
4.4.9.	Representing the same device in multiple networks	15
4.4.10.	Supporting client-configured and system-controlled network topology	16
4.4.11.	Identifiers of string or URI type	17
5.	Interactions with Other YANG Modules	18
6.	YANG Modules	18
6.1.	Defining the Abstract Network: ietf-network.yang	18
6.2.	Creating Abstract Network Topology: ietf-network-topology.yang	23
7.	IANA Considerations	29
8.	Security Considerations	30
9.	Contributors	32
10.	Acknowledgements	32
11.	References	32
11.1.	Normative References	32

11.2.	Informative References	33
Appendix A.	Model Use Cases	35
A.1.	Fetching Topology from a Network Element	35
A.2.	Modifying TE Topology Imported from an Optical Controller	35
A.3.	Annotating Topology for Local Computation	36

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

A.4.	SDN Controller-Based Configuration of Overlays on Top of Underlays	36
Appendix B.	Companion YANG models for non-NMDA compliant implementations	36
B.1.	YANG Model for Network State	37
B.2.	YANG Data Model for Network Topology State	41
Appendix C.	An Example	47
	Authors' Addresses	51

[1.](#) Introduction

This document introduces an abstract (base) YANG [[RFC7950](#)] data model [[RFC3444](#)] to represent networks and topologies. The data model is divided into two parts. The first part of the data model defines a network data model that enables the definition of network hierarchies (i.e. network stacks of networks that are layered on top of each other) and to maintain an inventory of nodes contained in a network. The second part of the data model augments the basic network data model with information to describe topology information. Specifically, it adds the concepts of links and termination points to describe how nodes in a network are connected to each other. Moreover the data model introduces vertical layering relationships between networks that can be augmented to cover both network inventories and network/service topologies.

While it would be possible to combine both parts into a single data model, the separation facilitates integration of network topology and network inventory data models, because it allows to augment network inventory information separately and without concern for topology into the network data model.

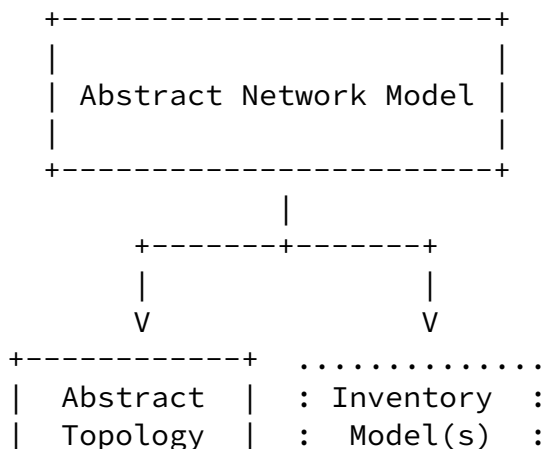
The data model can be augmented to describe the specifics of particular types of networks and topologies. For example, an augmenting data model can provide network node information with attributes that are specific to a particular network type. Examples of augmenting models include data models for Layer 2 network

topologies, Layer 3 network topologies, such as Unicast IGP, IS-IS [RFC1195] and OSPF [RFC2328], traffic engineering (TE) data [RFC3209], or any of the variety of transport and service topologies. Information specific to particular network types will be captured in separate, technology-specific data models.

The basic data models introduced in this document are generic in nature and can be applied to many network and service topologies and inventories. The data models allow applications to operate on an inventory or topology of any network at a generic level, where the specifics of particular inventory/topology types are not required. At the same time, where data specific to a network type does come

into play and the data model is augmented, the instantiated data still adheres to the same structure and is represented in a consistent fashion. This also facilitates the representation of network hierarchies and dependencies between different network components and network types.

The abstract (base) network YANG module introduced in this document, entitled "ietf-network.yang", contains a list of abstract network nodes and defines the concept of network hierarchy (network stack). The abstract network node can be augmented in inventory and topology data models with inventory and topology specific attributes. Network hierarchy (stack) allows any given network to have one or more "supporting networks". The relationship of the base network data model, the inventory data models and the topology data models is shown in the following figure (dotted lines in the figure denote possible augmentations to models defined in this document).



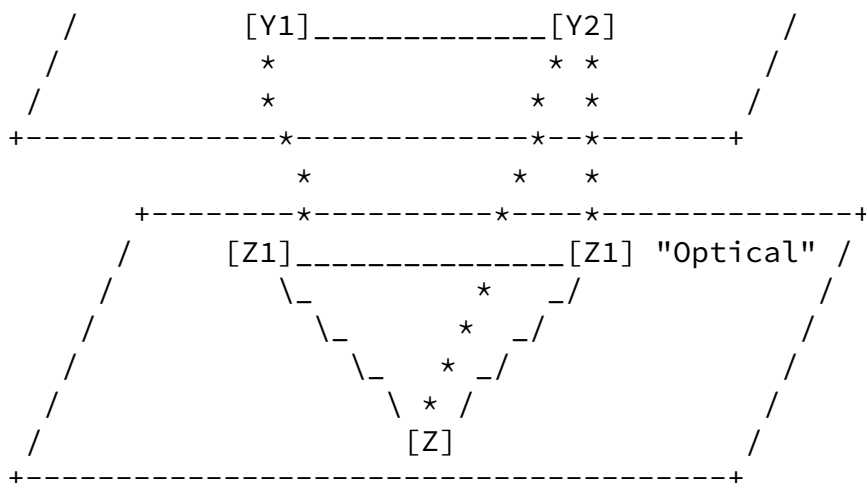
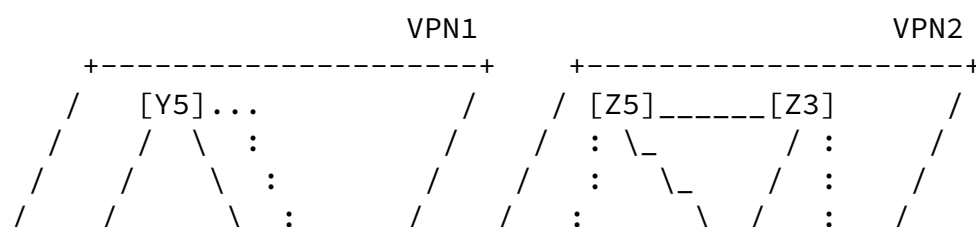


Figure 2: Topology hierarchy (stack) example

The figure shows three topology levels. At top, the "Service" topology shows relationships between service entities, such as service functions in a service chain. The "L3" topology shows network elements at Layer 3 (IP) and the "Optical" topology shows network elements at Layer 1. Service functions in the "Service" topology are mapped onto network elements in the "L3" topology, which in turn are mapped onto network elements in the "Optical" topology. The figure shows two Service Functions (X1 and X3) mapping onto a single L3 network element (Y2); this could happen, for example, if two service functions reside in the same VM (or server) and share the

same set of network interfaces. The figure shows a single "L3" network element (Y2) mapped onto multiple "Optical" network elements (Z and Z1). This could happen, for example, if a single IP router attaches to multiple Reconfigurable Optical Add/Drop Multiplexers (ROADMs) in the optical domain.

Another example of a service topology stack is shown in the following figure.



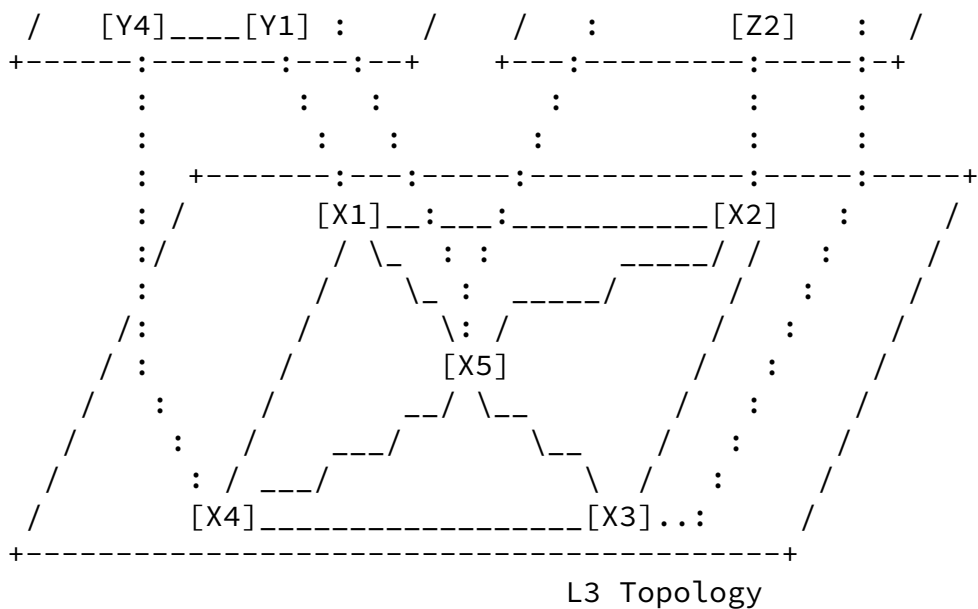


Figure 3: Topology hierarchy (stack) example

The figure shows two VPN service topologies (VPN1 and VPN2) instantiated over a common L3 topology. Each VPN service topology is mapped onto a subset of nodes from the common L3 topology.

There are multiple applications for such a data model. For example, within the context of I2RS, nodes within the network can use the data model to capture their understanding of the overall network topology and expose it to a network controller. A network controller can then use the instantiated topology data to compare and reconcile its own view of the network topology with that of the network elements that it controls. Alternatively, nodes within the network could propagate this understanding to compare and reconcile this understanding either among themselves or with help of a controller. Beyond the network element and the immediate context of I2RS itself, a network

controller might even use the data model to represent its view of the topology that it controls and expose it to applications north of itself. Further use cases that the data model can be applied to are described in [I-D.[draft-ietf-i2rs-usecase-reqs-summary](#)].

In this data model, a network is categorized as either system controlled or not. If a network is system controlled, then it is automatically populated by the server and represents dynamically

learned information that can be read from the operational datastore. The data model can also be used to create or modify network topologies such as might be associated with an inventory or with an overlay network. Such a network is not system controlled but configured by a client.

The data model allows a network to refer to a supporting-network, supporting-nodes, supporting-links, etc. The data model also allows to layer a network that is configured on top of one that is system controlled. This permits the configuration of overlay networks on top of networks that are discovered. Specifically, this data model is structured to support being implemented as part of the ephemeral datastore [I-D.[draft-ietf-netmod-revised-datastores](#)], defined as requirement Ephemeral-REQ-03 in [I-D.[draft-ietf-i2rs-ephemeral-state](#)]. This allows network topology data that is written, i.e. configured by a client and not system controlled, to refer to a dynamically learned data that is controlled by the system, not configured by a client. A simple use case might involve creating an overlay network that is supported by the dynamically discovered IP routed network topology. When an implementation places written data for this data model in the ephemeral data store, then such a network MAY refer to another network that is system controlled.

2. Key Words

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [BCP 14](#) [[RFC2119](#)] [[RFC8174](#)] when, and only when, they appear in all capitals, as shown here.

3. Definitions and Acronyms

Datastore: A conceptual place to store and access information. A datastore might be implemented, for example, using files, a database, flash memory locations, or combinations thereof. A datastore maps to an instantiated YANG data tree. (Definition adopted from [I-D.[draft-ietf-netmod-revised-datastores](#)])

Data subtree: An instantiated data node and the data nodes that are

hierarchically contained within it.

IGP: Interior Gateway Protocol

IS-IS: Intermediate System to Intermediate System protocol

OSPF: Open Shortest Path First, a link state routing protocol

URI: Uniform Resource Identifier

[4.](#) Model Structure Details

[4.1.](#) Base Network Model

The abstract (base) network data model is defined in the `ietf-network.yang` module. Its structure is shown in the following figure. The notation syntax follows [I-D.[draft-ietf-netmod-yang-tree-diagrams](#)].

```
module: ietf-network
+--rw networks
  +--rw network* [network-id]
    +--rw network-id          network-id
    +--rw network-types
    +--rw supporting-network* [network-ref]
  | +--rw network-ref        -> /networks/network/network-id
  +--rw node* [node-id]
    +--rw node-id            node-id
    +--rw supporting-node* [network-ref node-ref]
      +--rw network-ref      -> ../../../../supporting-network/ +
      |                      network-ref
      +--rw node-ref         -> /networks/network/node/node-id
```

Figure 4: The structure of the abstract (base) network data model

The data model contains a container with a list of networks. Each network is captured in its own list entry, distinguished via a `network-id`.

A network has a certain type, such as L2, L3, OSPF or IS-IS. A network can even have multiple types simultaneously. The type, or types, are captured underneath the container "network-types". In this module it serves merely as an augmentation target; network-specific modules will later introduce new data nodes to represent new

network types below this target, i.e. insert them below "network-types" by ways of YANG augmentation.

When a network is of a certain type, it will contain a corresponding data node. Network types SHOULD always be represented using presence containers, not leafs of empty type. This allows the representation of hierarchies of network subtypes within the instance information. For example, an instance of an OSPF network (which, at the same time, is a layer 3 unicast IGP network) would contain underneath "network-types" another presence container "l3-unicast-igp-network", which in turn would contain a presence container "ospf-network". Actual examples of this pattern can be found in [I-D.[draft-ietf-i2rs-yang-l3-topology](#)].

A network can in turn be part of a hierarchy of networks, building on top of other networks. Any such networks are captured in the list "supporting-network". A supporting network is in effect an underlay network.

Furthermore, a network contains an inventory of nodes that are part of the network. The nodes of a network are captured in their own list. Each node is identified relative to its containing network by a node-id.

It should be noted that a node does not exist independently of a network; instead it is a part of the network that it is contained in. In cases where the same entity takes part in multiple networks, or at multiple layers of a networking stack, the same entity will be represented by multiple nodes, one for each network. In other words, the node represents an abstraction of the device for the particular network that it is a part of. To represent that the same entity or same device is part of multiple topologies or networks, it is possible to create one "physical" network with a list of nodes for each of the devices or entities. This (physical) network, respectively the (entities) nodes in that network, can then be referred to as underlay network and nodes from the other (logical) networks and nodes, respectively. Note that the data model allows for the definition of more than one underlay network (and node), allowing for simultaneous representation of layered network and service topologies and their physical instantiation.

Similar to a network, a node can be supported by other nodes, and map onto one or more other nodes in an underlay network. This is captured in the list "supporting-node". The resulting hierarchy of nodes allows also for the representation of device stacks, where a node at one level is supported by a set of nodes at an underlying

level. For example, a "router" node might be supported by a node representing a route processor and separate nodes for various line

cards and service modules, a virtual router might be supported or hosted on a physical device represented by a separate node, and so on.

Network data of a network at a particular layer can come into being in one of two ways. In one way, network data is configured by client applications, for example in case of overlay networks that are configured by an SDN Controller application. In another way, it is automatically controlled by the system, in case of networks that can be discovered. It is possible for a configured (overlay) network to refer to a (discovered) underlay network.

The revised datastore architecture [I-D.[draft-ietf-netmod-revised-datastores](#)] is used to account for those possibilities. Specifically, for each network, the origin of its data is indicated per the "origin" metadata annotation - "intended" for data that was configured by a client application, "learned" for data that is discovered. Network data that is discovered is automatically populated as part of the operational datastore. Network data that is configured is part of the configuration and intended datastores, respectively. Configured network data that is actually in effect is in addition reflected in the operational datastore. Data in the operational datastore will always have complete referential integrity. Should a configured data item (such as a node) have a dangling reference that refers to a non-existing data item (such as a supporting node), the configured data item will automatically be removed from the operational datastore and thus only appear in the intended datastore. It will be up to the client application to resolve the situation and ensure that the reference to the supporting resources is configured properly.

[4.2.](#) Base Network Topology Data Model

The abstract (base) network topology data model is defined in the "ietf-network-topology.yang" module. It builds on the network data model defined in the "ietf-network.yang" module, augmenting it with links (defining how nodes are connected) and termination-points (which anchor the links and are contained in nodes). The structure of the network topology module is shown in the following figure. The

notation syntax follows [I-D.[draft-ietf-netmod-yang-tree-diagrams](#)].

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

```
module: ietf-network-topology
augment /nw:networks/nw:network:
  +--rw link* [link-id]
    +--rw link-id          link-id
    +--rw source
      | +--rw source-node? -> ../../../../nw:node/node-id
      | +--rw source-tp?  -> ../../../../nw:node[nw:node-id=current()/+
      |                   ../../source-node]/termination-point/tp-id
    +--rw destination
      | +--rw dest-node?  -> ../../../../nw:node/node-id
      | +--rw dest-tp?   -> ../../../../nw:node[nw:node-id=current()/+
      |                   ../../dest-node]/termination-point/tp-id
    +--rw supporting-link* [network-ref link-ref]
      +--rw network-ref   -> ../../../../nw:supporting-network/+
      |                   network-ref
      +--rw link-ref      -> /nw:networks/network+
                           [nw:network-id=current()/../network-ref]/+
                           link/link-id
augment /nw:networks/nw:network/nw:node:
  +--rw termination-point* [tp-id]
    +--rw tp-id          tp-id
    +--rw supporting-termination-point* [network-ref node-ref tp-ref]
      +--rw network-ref  -> ../../../../nw:supporting-node/network-ref
      +--rw node-ref     -> ../../../../nw:supporting-node/node-ref
      +--rw tp-ref       -> /nw:networks/network[nw:network-id=+
                           current()/../network-ref]/node+
                           [nw:node-id=current()/../node-ref]/+
                           termination-point/tp-id
```

Figure 5: The structure of the abstract (base) network topology data model

A node has a list of termination points that are used to terminate links. An example of a termination point might be a physical or logical port or, more generally, an interface.

Like a node, a termination point can in turn be supported by an underlying termination point, contained in the supporting node of the underlay network.

A link is identified by a link-id that uniquely identifies the link within a given topology. Links are point-to-point and unidirectional. Accordingly, a link contains a source and a destination. Both source and destination reference a corresponding node, as well as a termination point on that node. Similar to a node, a link can map onto one or more links in an underlay topology (which are terminated by the corresponding underlay termination points). This is captured in the list "supporting-link".

[4.3.](#) Extending the data model

In order to derive a data model for a specific type of network, the base data model can be extended. This can be done roughly as follows: for the new network type, a new YANG module is introduced. In this module, a number of augmentations are defined against the network and network-topology YANG modules.

We start with augmentations against the `ietf-network.yang` module. First, a new network type needs to be defined. For this, a presence container that resembles the new network type is defined. It is inserted by means of augmentation below the `network-types` container. Subsequently, data nodes for any network-type specific node parameters are defined and augmented into the node list. The new data nodes can be defined as conditional ("when") on the presence of the corresponding network type in the containing network. In cases where there are any requirements or restrictions in terms of network hierarchies, such as when a network of a new network-type requires a specific type of underlay network, it is possible to define corresponding constraints as well and augment the `supporting-network` list accordingly. However, care should be taken to avoid excessive definitions of constraints.

Subsequently, augmentations are defined against `ietf-network-topology.yang`. Data nodes are defined both for link parameters, as

well as termination point parameters, that are specific to the new network type. Those data nodes are inserted by way of augmentation into the link and termination-point lists, respectively. Again, data nodes can be defined as conditional on the presence of the corresponding network-type in the containing network, by adding a corresponding "when"-statement.

It is possible, but not required, to group data nodes for a given network-type under a dedicated container. Doing so introduces further structure, but lengthens data node path names.

In cases where a hierarchy of network types is defined, augmentations can in turn be applied against augmenting modules, with the module of a network "sub-type" augmenting the module of a network "super-type".

[4.4.](#) Discussion and selected design decisions

[4.4.1.](#) Container structure

Rather than maintaining lists in separate containers, the data model is kept relatively flat in terms of its containment structure. Lists of nodes, links, termination-points, and supporting-nodes, supporting-links, and supporting-termination-points are not kept in

separate containers. Therefore, path specifiers used to refer to specific nodes, be it in management operations or in specifications of constraints, can remain relatively compact. Of course, this means there is no separate structure in instance information that separates elements of different lists from one another. Such structure is semantically not required, although it might enhance human readability in some cases.

[4.4.2.](#) Underlay hierarchies and mappings

To minimize assumptions of what a particular entity might actually represent, mappings between networks, nodes, links, and termination points are kept strictly generic. For example, no assumptions are made whether a termination point actually refers to an interface, or whether a node refers to a specific "system" or device; the data model at this generic level makes no provisions for that.

Where additional specifics about mappings between upper and lower

layers are required, those can be captured in augmenting modules. For example, to express that a termination point in a particular network type maps to an interface, an augmenting module can introduce an augmentation to the termination point which introduces a leaf of type `ifref` that references the corresponding interface [RFC7223]. Similarly, if a node maps to a particular device or network element, an augmenting module can augment the node data with a leaf that references the network element.

It is possible for links at one level of a hierarchy to map to multiple links at another level of the hierarchy. For example, a VPN topology might model VPN tunnels as links. Where a VPN tunnel maps to a path that is composed of a chain of several links, the link will contain a list of those supporting links. Likewise, it is possible for a link at one level of a hierarchy to aggregate a bundle of links at another level of the hierarchy.

[4.4.3. Dealing with changes in underlay networks](#)

It is possible for a network to undergo churn even as other networks are layered on top of it. When a supporting node, link, or termination point is deleted, the supporting leafrefs in the overlay will be left dangling. To allow for this possibility, the data model makes use of the "require-instance" construct of YANG 1.1 [RFC7950].

A dangling leafref of a configured object leaves the corresponding instance in a state in which it lacks referential integrity, rendering it in effect inoperational. Any corresponding object instance is therefore removed from the operational datastore until the situation has been resolved, i.e. until either the supporting

object is added to the operational datastore, or until the instance is reconfigured to refer to another object that is actually reflected in the operational datastore. It does remain part of the intended datastore.

It is the responsibility of the application maintaining the overlay to deal with the possibility of churn in the underlay network. When a server receives a request to configure an overlay network, it SHOULD validate whether supporting nodes/links/tps refer to nodes in the underlay are actually in existence, i.e. nodes which are reflected in the operational datastore. Configuration requests in

which supporting nodes/links/tps refer to objects currently not in existence SHOULD be rejected. It is the responsibility of the application to update the overlay when a supporting node/link/tp is deleted at a later point in time. For this purpose, an application might subscribe to updates when changes to the underlay occur, for example using mechanisms defined in [I-D.[draft-ietf-netconf-yang-push](#)].

[4.4.4.](#) Use of groupings

The data model makes use of groupings, instead of simply defining data nodes "in-line". This makes it easier to include the corresponding data nodes in notifications, which then do not need to respecify each data node that is to be included. The tradeoff for this is that it makes the specification of constraints more complex, because constraints involving data nodes outside the grouping need to be specified in conjunction with a "uses" statement where the grouping is applied. This also means that constraints and XPath-statements need to be specified in such a way that they navigate "down" first and select entire sets of nodes, as opposed to being able to simply specify them against individual data nodes.

[4.4.5.](#) Cardinality and directionality of links

The topology data model includes links that are point-to-point and unidirectional. It does not directly support multipoint and bidirectional links. While this may appear as a limitation, it does keep the data model simple, generic, and allows it to very easily be subjected to applications that make use of graph algorithms. Bidirectional connections can be represented through pairs of unidirectional links. Multipoint networks can be represented through pseudo-nodes (similar to IS-IS, for example). By introducing hierarchies of nodes, with nodes at one level mapping onto a set of other nodes at another level, and introducing new links for nodes at that level, topologies with connections representing non-point-to-point communication patterns can be represented.

[4.4.6.](#) Multihoming and link aggregation

Links are terminated by a single termination point, not sets of termination points. Connections involving multihoming or link

aggregation schemes need to be represented using multiple point-to-point links, then defining a link at a higher layer that is supported by those individual links.

[4.4.7.](#) Mapping redundancy

In a hierarchy of networks, there are nodes mapping to nodes, links mapping to links, and termination points mapping to termination points. Some of this information is redundant. Specifically, if the link-to-links mapping is known, and the termination points of each link are known, termination point mapping information can be derived via transitive closure and does not have to be explicitly configured. Nonetheless, in order to not constrain applications regarding which mappings they want to configure and which should be derived, the data model does provide for the option to configure this information explicitly. The data model includes integrity constraints to allow for validating for consistency.

[4.4.8.](#) Typing

A network's network types are represented using a container which contains a data node for each of its network types. A network can encompass several types of network simultaneously, hence a container is used instead of a case construct, with each network type in turn represented by a dedicated presence container itself. The reason for not simply using an empty leaf, or even simpler, do away even with the network container and just use a leaf-list of network-type instead, is to be able to represent "class hierarchies" of network types, with one network type refining the other. Network-type specific containers are to be defined in the network-specific modules, augmenting the network-types container.

[4.4.9.](#) Representing the same device in multiple networks

One common requirement concerns the ability to represent that the same device can be part of multiple networks and topologies. However, the data model defines a node as relative to the network that it is contained in. The same node cannot be part of multiple topologies. In many cases, a node will be the abstraction of a particular device in a network. To reflect that the same device is part of multiple topologies, the following approach might be chosen: A new type of network to represent a "physical" (or "device") network is introduced, with nodes representing devices. This network forms

an underlay network for logical networks above it, with nodes of the logical network mapping onto nodes in the physical network.

This scenario is depicted in the following figure. It depicts three networks with two nodes each. A physical network P consists of an inventory of two nodes, D1 and D2, each representing a device. A second network, X, has a third network, Y, as its underlay. Both X and Y also have the physical network P as underlay. X1 has both Y1 and D1 as underlay nodes, while Y1 has D1 as underlay node. Likewise, X2 has both Y2 and D2 as underlay nodes, while Y2 has D2 as underlay node. The fact that X1 and Y1 are both instantiated on the same physical node D1 can be easily derived.

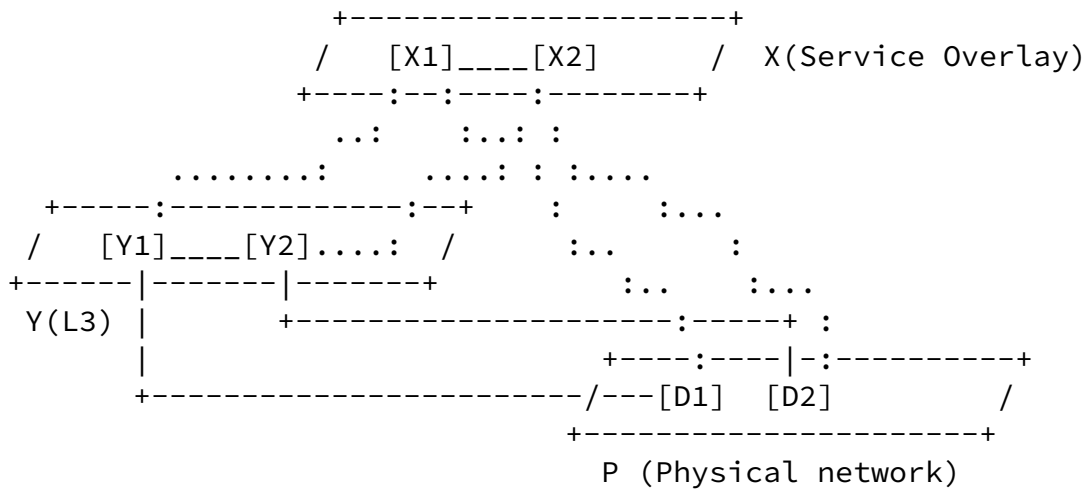


Figure 6: Topology hierarchy example - multiple underlays

In the case of a physical network, nodes represent physical devices and termination points physical ports. It should be noted that it is also possible to augment the data model for a physical network-type, defining augmentations that have nodes reference system information and termination points reference physical interfaces, in order to provide a bridge between network and device models.

4.4.10. Supporting client-configured and system-controlled network topology

YANG requires data nodes to be designated as either configuration ("config true") or operational data ("config false"), but not both, yet it is important to have all network information, including vertical cross-network dependencies, captured in one coherent data model. In most cases, network topology information is discovered about a network; the topology is considered a property of the network that is reflected in the data model. That said, certain types of

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

topology need to also be configurable by an application, such as in the case of overlay topologies.

The YANG data model for network topology designates all data as "config true". The distinction between data that is actually configured and data that is in effect, including data that is discovered about the network, is provided through the datastores introduced as part of the Network Management Datastore Architecture, NMDA [I-D.[draft-ietf-netmod-revised-datastores](#)]. Network topology data that is discovered is automatically populated as part of the operational datastore, <operational>. It is "system controlled". Network topology that is configured is instantiated as part of a configuration datastore, e.g. <intended>. Only when it has actually taken effect, it is also instantiated as part of the operational datastore, i.e. <operational>.

Configured network topology will in general refer to an underlay topology and include layering information, such as the supporting node(s) underlying a node, supporting link(s) underlying a link, and supporting termination point(s) underlying a termination point. The supporting objects must be instantiated in the operational datastore in order for the dependent overlay object to be reflected in the operational datastore. Should a configured data item (such as a node) have a dangling reference that refers to a non-existing data item (such as a supporting node), the configured data item will automatically be removed from <operational> and show up only in the <intended>. It will be up to the client application to resolve the situation and ensure that the reference to the supporting resources is configured properly.

For each network, the origin of its data is indicated per the "origin" metadata [[RFC7952](#)] annotation defined in [I-D.[draft-ietf-netmod-revised-datastores](#)]. In general, the origin of discovered network data is "learned"; the origin of configured network data is "intended".

[4.4.11](#). Identifiers of string or URI type

The current data model defines identifiers of nodes, networks, links, and termination points as URIs. An alternative would define them as

strings.

The case for strings is that they will be easier to implement. The reason for choosing URIs is that the topology/node/tp exists in a larger context, hence it is useful to be able to correlate identifiers across systems. While strings, being the universal data type, are easier for human beings, they also muddle things. What typically happens is that strings have some structure which is

magically assigned and the knowledge of this structure has to be communicated to each system working with the data. A URI makes the structure explicit and also attaches additional semantics: the URI, unlike a free-form string, can be fed into a URI resolver, which can point to additional resources associated with the URI. This property is important when the topology data is integrated into a larger, more complex system.

[5.](#) Interactions with Other YANG Modules

The data model makes use of data types that have been defined in [\[RFC6991\]](#).

This is a protocol independent YANG data model with topology information. It is separate from and not linked with data models that are used to configure routing protocols or routing information. This includes e.g. data model "ietf-routing" [\[RFC8022\]](#).

The data model obeys the requirements for the ephemeral state found in the document [I-D.[draft-ietf-i2rs-ephemeral-state](#)]. For ephemeral topology data that is system controlled, the process tasked with maintaining topology information will load information from the routing process (such as OSPF) into the <operational> without relying on a configuration datastore.

[6.](#) YANG Modules

[6.1.](#) Defining the Abstract Network: ietf-network.yang

NOTE TO RFC EDITOR: Please change the date in the file name after the CODE BEGINS statement to the date of publication when published.

```
<CODE BEGINS> file "ietf-network@2017-11-15.yang"
```

```
module ietf-network {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-network";
  prefix nw;

  import ietf-inet-types {
    prefix inet;
    reference "RFC 6991";
  }

  organization
    "IETF I2RS (Interface to the Routing System) Working Group";

  contact
    "WG Web:      <http://tools.ietf.org/wg/i2rs/>
```

Clemm, et al.

Expires May 19, 2018

[Page 18]

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](https://tools.ietf.org/html/draft-ietf-i2rs-yang-network-topo-18.txt) November 2017

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description

"This module defines a common base data model for a collection of nodes in a network. Node definitions are further used in network topologies and inventories.

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This version of this YANG module is part of [draft-ietf-i2rs-yang-network-topo-18](#); see the RFC itself for full legal notices.

NOTE TO RFC EDITOR: Please replace above reference to [draft-ietf-i2rs-yang-network-topo-18](#) with RFC number when published (i.e. RFC xxxx).";

```
revision 2017-11-15 {
  description
    "Initial revision.
    NOTE TO RFC EDITOR:
    (1) Please replace the following reference
```

```
    to draft-ietf-i2rs-yang-network-topo-18 with
    RFC number when published (i.e. RFC xxxx).
    (2) Please replace the date in the revision statement with the
    date of publication when published. ";
  reference
    "draft-ietf-i2rs-yang-network-topo-18";
}
```

```
typedef node-id {
  type inet:uri;
  description
    "Identifier for a node. The precise structure of the node-id
    will be up to the implementation. Some implementations MAY
    for example, pick a uri that includes the network-id as
    part of the path. The identifier SHOULD be chosen such that
    the same node in a real network topology will always be
    identified through the same identifier, even if the data model
    is instantiated in separate datastores. An implementation MAY
    choose to capture semantics in the identifier, for example to
```

```

        indicate the type of node.";
    }

typedef network-id {
    type inet:uri;
    description
        "Identifier for a network. The precise structure of the
        network-id will be up to an implementation.
        The identifier SHOULD be chosen such that the same network
        will always be identified through the same identifier,
        even if the data model is instantiated in separate datastores.
        An implementation MAY choose to capture semantics in the
        identifier, for example to indicate the type of network.";
}

grouping network-ref {
    description
        "Contains the information necessary to reference a network,
        for example an underlay network.";
    leaf network-ref {
        type leafref {
            path "/nw:networks/nw:network/nw:network-id";
            require-instance false;
        }
        description
            "Used to reference a network, for example an underlay
            network.";
    }
}

```

```

grouping node-ref {
    description
        "Contains the information necessary to reference a node.";
    leaf node-ref {
        type leafref {
            path "/nw:networks/nw:network[nw:network-id=current()/../"+
                "network-ref]/nw:node/nw:node-id";
            require-instance false;
        }
        description
            "Used to reference a node.
            Nodes are identified relative to the network they are

```

```

        contained in.";
    }
    uses network-ref;
}

container networks {
    description
        "Serves as top-level container for a list of networks.";
    list network {
        key "network-id";
        description
            "Describes a network.
            A network typically contains an inventory of nodes,
            topological information (augmented through
            network-topology data model), as well as layering
            information.";
        leaf network-id {
            type network-id;
            description
                "Identifies a network.";
        }
        container network-types {
            description
                "Serves as an augmentation target.
                The network type is indicated through corresponding
                presence containers augmented into this container.";
        }
        list supporting-network {
            key "network-ref";
            description
                "An underlay network, used to represent layered network
                topologies.";
            leaf network-ref {
                type leafref {
                    path "/nw:networks/nw:network/nw:network-id";
                    require-instance false;
                }
            }
        }
    }
}

```

```

    }
    description
        "References the underlay network.";
    }
}

```


6.2. Creating Abstract Network Topology: ietf-network-topology.yang

NOTE TO RFC EDITOR: Please change the date in the file name after the CODE BEGINS statement to the date of publication when published.

```
<CODE BEGINS> file "ietf-network-topology@2017-11-15.yang"
module ietf-network-topology {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-network-topology";
  prefix nt;

  import ietf-inet-types {
    prefix inet;
    reference
      "RFC 6991";
  }
  import ietf-network {
    prefix nw;
    reference
      "draft-ietf-i2rs-yang-network-topo-18
NOTE TO RFC EDITOR:
(1) Please replace above reference to
draft-ietf-i2rs-yang-network-topo-18 with RFC
number when published (i.e. RFC xxxx).
(2) Please replace the date in the revision statement with the
date of publication when published.";
  }

  organization
    "IETF I2RS (Interface to the Routing System) Working Group";

  contact
    "WG Web:      <http://tools.ietf.org/wg/i2rs/>
    WG List:     <mailto:i2rs@ietf.org>

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    Editor:      Nitin Bahadur
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    Editor:      Hariharan Ananthakrishnan
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<mailto:hari@packetdesign.com>

Editor: Xufeng Liu
<mailto:Xufeng_Liu@jabil.com>";

description

"This module defines a common base model for network topology, augmenting the base network data model with links to connect nodes, as well as termination points to terminate links on nodes.

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This version of this YANG module is part of [draft-ietf-i2rs-yang-network-topo-18](#); see the RFC itself for full legal notices.

NOTE TO RFC EDITOR: Please replace above reference to [draft-ietf-i2rs-yang-network-topo-18](#) with RFC number when published (i.e. RFC xxxx).";

```
revision 2017-11-15 {
  description
    "Initial revision.
    NOTE TO RFC EDITOR: Please replace the following reference
    to draft-ietf-i2rs-yang-network-topo-18 with
    RFC number when published (i.e. RFC xxxx).";
  reference
    "draft-ietf-i2rs-yang-network-topo-18";
}

typedef link-id {
  type inet:uri;
  description
    "An identifier for a link in a topology.
```

The precise structure of the link-id will be up to the implementation. The identifier SHOULD be chosen such that the same link in a real network topology will always be identified through the same identifier, even if the data model is instantiated in separate datastores. An implementation MAY choose to capture

```
    semantics in the identifier, for example to indicate the type
    of link and/or the type of topology that the link is a part
    of.";
}

typedef tp-id {
  type inet:uri;
  description
    "An identifier for termination points (TPs) on a node.
    The precise structure of the tp-id
    will be up to the implementation.
    The identifier SHOULD be chosen such that the same termination
    point in a real network topology will always be identified
    through the same identifier, even if the data model is
    instantiated in separate datastores. An implementation MAY
    choose to capture semantics in the identifier, for example to
    indicate the type of termination point and/or the type of node
    that contains the termination point.";
}

grouping link-ref {
  description
    "This grouping can be used to reference a link in a specific
    network. While it is not used in this module, it is defined
    here for the convenience of augmenting modules.";
  leaf link-ref {
    type leafref {
      path "/nw:networks/nw:network[nw:network-id=current()/../"+
        "network-ref]/nt:link/nt:link-id";
      require-instance false;
    }
  }
  description
    "A type for an absolute reference a link instance.
    (This type should not be used for relative references.
    In such a case, a relative path should be used instead.)";
```

```

    }
    uses nw:network-ref;
}

grouping tp-ref {
  description
    "This grouping can be used to references a termination point
    in a specific node. While it is not used in this module, it
    is defined here for the convenience of augmenting modules.";
  leaf tp-ref {
    type leafref {
      path "/nw:networks/nw:network[nw:network-id=current()/../"+
        "network-ref]/nw:node[nw:node-id=current()/../"+

```

```

    "node-ref]/nt:termination-point/nt:tp-id";
    require-instance false;
  }
  description
    "A type for an absolute reference to a termination point.
    (This type should not be used for relative references.
    In such a case, a relative path should be used instead.)";
}
uses nw:node-ref;
}

augment "/nw:networks/nw:network" {
  description
    "Add links to the network data model.";
  list link {
    key "link-id";
    description
      "A network link connects a local (source) node and
      a remote (destination) node via a set of
      the respective node's termination points.
      It is possible to have several links between the same
      source and destination nodes. Likewise, a link could
      potentially be re-homed between termination points.
      Therefore, in order to ensure that we would always know
      to distinguish between links, every link is identified by
      a dedicated link identifier. Note that a link models a
      point-to-point link, not a multipoint link.";
    leaf link-id {

```

```

type link-id;
description
  "The identifier of a link in the topology.
  A link is specific to a topology to which it belongs.";
}
container source {
  description
    "This container holds the logical source of a particular
    link.";
  leaf source-node {
    type leafref {
      path "../..../nw:node/nw:node-id";
      require-instance false;
    }
    description
      "Source node identifier, must be in same topology.";
  }
  leaf source-tp {
    type leafref {
      path "../..../nw:node[nw:node-id=current()/../"+

```

```

      "source-node]/termination-point/tp-id";
      require-instance false;
    }
    description
      "Termination point within source node that terminates
      the link.";
  }
}
container destination {
  description
    "This container holds the logical destination of a
    particular link.";
  leaf dest-node {
    type leafref {
      path "../..../nw:node/nw:node-id";
      require-instance false;
    }
    description
      "Destination node identifier, must be in the same
      network.";
  }
}

```

```

leaf dest-tp {
  type leafref {
    path "../..../nw:node[nw:node-id=current()/../"+
      "dest-node]/termination-point/tp-id";
    require-instance false;
  }
  description
    "Termination point within destination node that
    terminates the link.";
}
}
list supporting-link {
  key "network-ref link-ref";
  description
    "Identifies the link, or links, that this link
    is dependent on.";
  leaf network-ref {
    type leafref {
      path "../..../nw:supporting-network/nw:network-ref";
      require-instance false;
    }
    description
      "This leaf identifies in which underlay topology
      the supporting link is present.";
  }
  leaf link-ref {
    type leafref {

```

```

    path "/nw:networks/nw:network[nw:network-id=current()/"+
      " ../network-ref]/link/link-id";
    require-instance false;
  }
  description
    "This leaf identifies a link which is a part
    of this link's underlay. Reference loops in which
    a link identifies itself as its underlay, either
    directly or transitively, are not allowed.";
}
}
}
}
augment "/nw:networks/nw:network/nw:node" {

```

```

description
  "Augment termination points which terminate links.
  Termination points can ultimately be mapped to interfaces.";
list termination-point {
  key "tp-id";
  description
    "A termination point can terminate a link.
    Depending on the type of topology, a termination point
    could, for example, refer to a port or an interface.";
  leaf tp-id {
    type tp-id;
    description
      "Termination point identifier.";
  }
}
list supporting-termination-point {
  key "network-ref node-ref tp-ref";
  description
    "This list identifies any termination points that
    the termination point is dependent on, or maps onto.
    Those termination points will themselves be contained
    in a supporting node.
    This dependency information can be inferred from
    the dependencies between links. For this reason,
    this item is not separately configurable. Hence no
    corresponding constraint needs to be articulated.
    The corresponding information is simply provided by the
    implementing system.";
  leaf network-ref {
    type leafref {
      path "../..../nw:supporting-node/nw:network-ref";
      require-instance false;
    }
    description
      "This leaf identifies in which topology the

```

```

    supporting termination point is present.";
  }
  leaf node-ref {
    type leafref {
      path "../..../nw:supporting-node/nw:node-ref";
      require-instance false;
    }
  }

```


XML: N/A; the requested URI is an XML namespace.

This document registers the following YANG modules in the "YANG Module Names" registry [[RFC6020](#)]:

NOTE TO THE RFC EDITOR: In the list below, please replace references to "[draft-ietf-i2rs-yang-network-topo-18](#) (RFC form)" with RFC number when published (i.e. RFC xxxx).

Name: ietf-network
Namespace: urn:ietf:params:xml:ns:yang:ietf-network
Prefix: nw
Reference: [draft-ietf-i2rs-yang-network-topo-18.txt](#) (RFC form)

Name: ietf-network-topology
Namespace: urn:ietf:params:xml:ns:yang:ietf-network-topology
Prefix: nt
Reference: [draft-ietf-i2rs-yang-network-topo-18.txt](#) (RFC form)

Name: ietf-network-state
Namespace: urn:ietf:params:xml:ns:yang:ietf-network-state
Prefix: nw-s
Reference: [draft-ietf-i2rs-yang-network-topo-18.txt](#) (RFC form)

Name: ietf-network-topology-state
Namespace: urn:ietf:params:xml:ns:yang:ietf-network-topology-state
Prefix: nt-s
Reference: [draft-ietf-i2rs-yang-network-topo-18.txt](#) (RFC form)

8. Security Considerations

The YANG modules defined in this document are designed to be accessed via network management protocols such as NETCONF [[RFC6241](#)] or RESTCONF [[RFC8040](#)]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [[RFC6242](#)]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [[RFC5246](#)].

The NETCONF access control model [[RFC6536](#)] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

The YANG modules define information that can be configurable in certain instances, for example in the case of overlay topologies that can be created by client applications. In such cases, a malicious client could introduce topologies that are undesired. Specifically, a malicious client could attempt to remove or add a node, a link, a

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

termination point, by creating or deleting corresponding elements in the node, link, and termination point lists, respectively. In the case of a topology that is learned, the server will automatically prohibit such misconfiguration attempts. In the case of a topology that is configured, i.e. whose origin is "intended", the undesired configuration could become effective and be reflected in the operational datastore, leading to disruption of services provided via this topology might be disrupted. For example, the topology could be "cut" or be configured in a suboptimal way, leading to increased consumption of resources in the underlay network due to resulting routing and bandwidth utilization inefficiencies. Likewise, it could lead to degradation of service levels as well as possibly disruption of service. For those reasons, it is important that the NETCONF access control model is vigorously applied to prevent topology misconfiguration by unauthorized clients.

Specifically, there are a number of data nodes defined in these YANG module that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. These are the subtrees and data nodes and their sensitivity/vulnerability in the ietf-network module:

- o network: A malicious client could attempt to remove or add a network in an attempt to remove an overlay topology, or create an unauthorized overlay.
- o supporting-network: A malicious client could attempt to disrupt the logical structure of the model, resulting in lack of overall data integrity and making it more difficult to, for example, troubleshoot problems rooted in the layering of network topologies.
- o node: A malicious client could attempt to remove or add a node from network, for example in order to sabotage the topology of a network overlay.
- o supporting-node: A malicious client could attempt to change the supporting-node in order to sabotage the layering of an overlay.

These are the subtrees and data nodes and their sensitivity/

vulnerability in the ietf-network-topology module:

- o link: A malicious client could attempt to remove a link from a topology, or add a new link, or manipulate the way the link is layered over supporting links, or modify the source or destination

of the link. Either way, the structure of the topology would be sabotaged, which could, for example, result in an overlay topology that is less than optimal.

- o termination-point: A malicious client could attempt to remove termination points from a node, or add "phantom" termination points to a node, or change the layering dependencies of termination points, again in an attempt to sabotage the integrity of a topology and potentially disrupt orderly operations of an overlay.

9. Contributors

The data model presented in this paper was contributed to by more people than can be listed on the author list. Additional contributors include:

- o Vishnu Pavan Beeram, Juniper
- o Ken Gray, Cisco
- o Tom Nadeau, Brocade
- o Tony Tkacik
- o Kent Watsen, Juniper
- o Aleksandr Zhdankin, Cisco

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Clemm, et al.

Expires May 19, 2018

[Page 32]

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

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Clemm, et al.

Expires May 19, 2018

[Page 33]

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

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[Appendix A](#). Model Use Cases

[A.1](#). Fetching Topology from a Network Element

In its simplest form, topology is learned by a network element (e.g., a router) through its participation in peering protocols (IS-IS, BGP, etc.). This learned topology can then be exported (e.g., to a Network Management System) for external utilization. Typically, any network element in a domain can be queried for its topology and expected to return the same result.

In a slightly more complex form, the network element may be a controller, either by nature of it having satellite or subtended devices hanging off of it, or in the more classical sense, such as special device designated to orchestrate the activities of a number

of other devices (e.g., an optical controller). In this case, the controller device is logically a singleton and must be queried distinctly.

It is worth noting that controllers can be built on top of controllers to establish a topology incorporating of all the domains within an entire network.

In all of the cases above, the topology learned by the network element is considered to be operational state data. That is, the data is accumulated purely by the network element's interactions with other systems and is subject to change dynamically without input or consent.

[A.2.](#) Modifying TE Topology Imported from an Optical Controller

Consider a scenario where an Optical Transport Controller presents its topology in abstract TE Terms to a Client Packet Controller. This Customized Topology (that gets merged into the Client's native topology) contains sufficient information for the path computing client to select paths across the optical domain according to its policies. If the Client determines (at any given point in time) that this imported topology does not exactly cater to its requirements, it may decide to request modifications to the topology. Such customization requests may include addition or deletion of topological elements or modification of attributes associated with existing topological elements. From the perspective of the Optical Controller, these requests translate into configuration changes to the exported abstract topology.

[A.3.](#) Annotating Topology for Local Computation

In certain scenarios, the topology learned by a controller needs to be augmented with additional attributes before running a computation algorithm on it. Consider the case where a path-computation application on the controller needs to take the geographic coordinates of the nodes into account while computing paths on the learned topology. If the learned topology does not contain these

coordinates, then these additional attributes must be configured on the corresponding topological elements.

[A.4.](#) SDN Controller-Based Configuration of Overlays on Top of Underlays

In this scenario, an SDN controller (for example, Open Daylight) maintains a view of the topology of the network that it controls based on information that it discovers from the network. In addition, it provides an application in which it configures and maintains an overlay topology.

The SDN Controller thus maintains two roles:

- o It is a client to the network.
- o It is a server to its own northbound applications and clients, e.g. an OSS.

In other words, one system's client (or controller, in this case) may be another system's server (or managed system).

In this scenario, the SDN controller maintains a consolidated data model of multiple layers of topology. This includes the lower layers of the network topology, built from information that is discovered from the network. It also includes upper layers of topology overlay, configurable by the controller's client, i.e. the OSS. To the OSS, the lower topology layers constitute "read-only" information. The upper topology layers need to be read-writable.

[Appendix B.](#) Companion YANG models for non-NMDA compliant implementations

The YANG modules defined in this document are designed to be used in conjunction with implementations that support the Network Management Datastore Architecture (NMDA) defined in [I-D.[draft-ietf-netmod-revised-datastores](#)]. In order to allow implementations to use the data model even in cases when NMDA is not supported, in the following two companion modules are defined that represent the operational state of networks and network topologies. The modules, `ietf-network-state` and `ietf-network-topology-state`,

in this document. However, all data nodes are non-configurable. They represent state that comes into being by either learning topology information from the network, or by applying configuration from the mirrored modules.

The companion modules, `ietf-network-state` and `ietf-network-topology-state`, are redundant and SHOULD NOT be supported by implementations that support NMDA. It is for this reason that the definitions are defined in an appendix.

As the structure of both modules mirrors that of their underlying modules, the YANG tree is not depicted separately.

[B.1.](#) YANG Model for Network State

NOTE TO RFC EDITOR: Please change the date in the file name after the CODE BEGINS statement to the date of the publication when published.

```
<CODE BEGINS> file "ietf-network-state@2017-11-15.yang"
module ietf-network-state {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-network-state";
  prefix nw-s;

  import ietf-network {
    prefix nw;
    reference
      "draft-ietf-i2rs-yang-network-topo-18
      NOTE TO RFC EDITOR: Please replace above reference to
      draft-ietf-i2rs-yang-network-topo-18 with RFC
      number when published (i.e. RFC xxxx).";
  }

  organization
    "IETF I2RS (Interface to the Routing System) Working Group";

  contact
    "WG Web:    <http://tools.ietf.org/wg/i2rs/>
    WG List:   <mailto:i2rs@ietf.org>

    Editor:    Alexander Clemm
               <mailto:ludwig@clemm.org>

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Editor: Xufeng Liu
<mailto:Xufeng_Liu@jabril.com>";

description

"This module defines a common base data model for a collection of nodes in a network. Node definitions are further used in network topologies and inventories. It represents information that is either learned and automatically populated, or information that results from applying configured network information configured per the ietf-network data model, mirroring the corresponding data nodes in this data model.

The data model mirrors ietf-network, but contains only read-only state data. The data model is not needed when the underlying implementation infrastructure supports the Network Management Datastore Architecture (NMDA).

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This version of this YANG module is part of [draft-ietf-i2rs-yang-network-topo-18](#); see the RFC itself for full legal notices.

NOTE TO RFC EDITOR: Please replace above reference to [draft-ietf-i2rs-yang-network-topo-18](#) with RFC number when published (i.e. RFC xxxx).";

```
revision 2017-11-15 {  
  description  
    "Initial revision.
```

NOTE TO RFC EDITOR:

(1) Please replace the following reference

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

```
to draft-ietf-i2rs-yang-network-topo-18 with
RFC number when published (i.e. RFC xxxx).
(2) Please replace the date in the revision statement with the
date of the publication when published.";
reference
"draft-ietf-i2rs-yang-network-topo-18";
}

grouping network-ref {
  description
    "Contains the information necessary to reference a network,
    for example an underlay network.";
  leaf network-ref {
    type leafref {
      path "/nw-s:networks/nw-s:network/nw-s:network-id";
      require-instance false;
    }
    description
      "Used to reference a network, for example an underlay
      network.";
  }
}

grouping node-ref {
  description
    "Contains the information necessary to reference a node.";
  leaf node-ref {
    type leafref {
      path "/nw-s:networks/nw-s:network[nw-s:network-id=current()"+
        "../network-ref]/nw-s:node/nw-s:node-id";
      require-instance false;
    }
    description
      "Used to reference a node.
      Nodes are identified relative to the network they are
      contained in.";
  }
  uses network-ref;
}
```

```

container networks {
  config false;
  description
    "Serves as top-level container for a list of networks.";
  list network {
    key "network-id";
    description
      "Describes a network."
  }
}

```

```

    "A network typically contains an inventory of nodes,
    topological information (augmented through
    network-topology data model), as well as layering
    information.";
  container network-types {
    description
      "Serves as an augmentation target.
      The network type is indicated through corresponding
      presence containers augmented into this container.";
  }
  leaf network-id {
    type nw:network-id;
    description
      "Identifies a network.";
  }
  list supporting-network {
    key "network-ref";
    description
      "An underlay network, used to represent layered network
      topologies.";
    leaf network-ref {
      type leafref {
        path "/nw-s:networks/nw-s:network/nw-s:network-id";
        require-instance false;
      }
      description
        "References the underlay network.";
    }
  }
  list node {
    key "node-id";
    description

```



```
<CODE BEGINS> file "ietf-network-topology-state@2017-11-15.yang"
module ietf-network-topology-state {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-network-topology-state";
  prefix nt-s;

  import ietf-network-state {
    prefix nw-s;
    reference
      "draft-ietf-i2rs-yang-network-topo-18
      NOTE TO RFC EDITOR: Please replace above reference to
      draft-ietf-i2rs-yang-network-topo-18 with RFC
      number when published (i.e. RFC xxxx).";
  }
  import ietf-network-topology {
    prefix nt;
    reference
      "draft-ietf-i2rs-yang-network-topo-18
      NOTE TO RFC EDITOR: Please replace above reference to
      draft-ietf-i2rs-yang-network-topo-18 with RFC
      number when published (i.e. RFC xxxx).";
  }
}
```

organization
"IETF I2RS (Interface to the Routing System) Working Group";

contact
"WG Web: <http://tools.ietf.org/wg/i2rs/>
WG List: <mailto:i2rs@ietf.org>

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Editor: Hariharan Ananthakrishnan
<mailto:hari@packetdesign.com>

Editor: Xufeng Liu
<mailto:Xufeng_Liu@jabril.com>";

description

"This module defines a common base data model for network topology state, representing topology that is either learned, or topology that results from applying topology that has been configured per the ietf-network-topology data model, mirroring the corresponding data nodes in this data model. It augments the base network state data model with links to connect nodes, as well as termination points to terminate links on nodes.

The data model mirrors ietf-network-topology, but contains only read-only state data. The data model is not needed when the underlying implementation infrastructure supports the Network Management Datastore Architecture (NMDA).

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This version of this YANG module is part of [draft-ietf-i2rs-yang-network-topo-18](#); see the RFC itself for full legal notices.

NOTE TO RFC EDITOR: Please replace above reference to [draft-ietf-i2rs-yang-network-topo-18](#) with RFC number when published (i.e. RFC xxxx).";

revision 2017-11-15 {
description
"Initial revision.

NOTE TO RFC EDITOR:

(1) Please replace the following reference to [draft-ietf-i2rs-yang-network-topo-18](#) with RFC number when published (i.e. RFC xxxx).

(2) Please replace the date in the revision statement with the date of publication when published.";

```
reference
  "draft-ietf-i2rs-yang-network-topo-18";
}

grouping link-ref {
  description
    "References a link in a specific network. While this grouping
     is not used in this module, it is defined here for the
     convenience of augmenting modules.";
  leaf link-ref {
    type leafref {
      path "/nw-s:networks/nw-s:network[nw-s:network-id=current()"+
        "/../network-ref]/nt-s:link/nt-s:link-id";
      require-instance false;
    }
    description
      "A type for an absolute reference a link instance.
       (This type should not be used for relative references.
        In such a case, a relative path should be used instead.)";
  }
  uses nw-s:network-ref;
}

grouping tp-ref {
  description
    "References a termination point in a specific node. While
     this grouping is not used in this module, it is defined here
     for the convenience of augmenting modules.";
  leaf tp-ref {
    type leafref {
      path "/nw-s:networks/nw-s:network[nw-s:network-id=current()"+
        "/../network-ref]/nw-s:node[nw-s:node-id=current()]/../"+
        "node-ref]/nt-s:termination-point/nt-s:tp-id";
      require-instance false;
    }
  }
}
```

```

    description
      "A type for an absolute reference to a termination point.
      (This type should not be used for relative references.
      In such a case, a relative path should be used instead.);
    }
  uses nw-s:node-ref;
}

augment "/nw-s:networks/nw-s:network" {
  description
    "Add links to the network data model.";
  list link {
    key "link-id";
    description
      "A network link connects a local (source) node and
      a remote (destination) node via a set of
      the respective node's termination points.
      It is possible to have several links between the same
      source and destination nodes. Likewise, a link could
      potentially be re-homed between termination points.
      Therefore, in order to ensure that we would always know
      to distinguish between links, every link is identified by
      a dedicated link identifier. Note that a link models a
      point-to-point link, not a multipoint link.";
    container source {
      description
        "This container holds the logical source of a particular
        link.";
      leaf source-node {
        type leafref {
          path "../..../nw-s:node/nw-s:node-id";
          require-instance false;
        }
        description
          "Source node identifier, must be in same topology.";
      }
      leaf source-tp {
        type leafref {
          path "../..../nw-s:node[nw-s:node-id=current()]/../"+
            "source-node]/termination-point/tp-id";
          require-instance false;
        }
        description
          "Termination point within source node that terminates

```

```
        the link.";
    }
}
container destination {
    description
        "This container holds the logical destination of a
        particular link.";
    leaf dest-node {
        type leafref {
            path "../..../nw-s:node/nw-s:node-id";
            require-instance false;
        }
        description
            "Destination node identifier, must be in the same
            network.";
    }
    leaf dest-tp {
        type leafref {
            path "../..../nw-s:node[nw-s:node-id=current()/../"+
                "dest-node]/termination-point/tp-id";
            require-instance false;
        }
        description
            "Termination point within destination node that
            terminates the link.";
    }
}
leaf link-id {
    type nt:link-id;
    description
        "The identifier of a link in the topology.
        A link is specific to a topology to which it belongs.";
}
list supporting-link {
    key "network-ref link-ref";
    description
        "Identifies the link, or links, that this link
        is dependent on.";
    leaf network-ref {
        type leafref {
            path "../..../nw-s:supporting-network/nw-s:network-ref";
            require-instance false;
        }
        description
            "This leaf identifies in which underlay topology
            the supporting link is present.";
    }
}
```

```
leaf link-ref {
```

Internet-Draft [draft-ietf-i2rs-yang-network-topo-18.txt](#) November 2017

```
    type leafref {
      path "/nw-s:networks/nw-s:network[nw-s:network-id="+
        "current()/../network-ref]/link/link-id";
      require-instance false;
    }
    description
      "This leaf identifies a link which is a part
      of this link's underlay. Reference loops in which
      a link identifies itself as its underlay, either
      directly or transitively, are not allowed.";
  }
}
}
}
augment "/nw-s:networks/nw-s:network/nw-s:node" {
  description
    "Augment termination points which terminate links.
    Termination points can ultimately be mapped to interfaces.";
  list termination-point {
    key "tp-id";
    description
      "A termination point can terminate a link.
      Depending on the type of topology, a termination point
      could, for example, refer to a port or an interface.";
    leaf tp-id {
      type nt:tp-id;
      description
        "Termination point identifier.";
    }
    list supporting-termination-point {
      key "network-ref node-ref tp-ref";
      description
        "This list identifies any termination points that
        the termination point is dependent on, or maps onto.
        Those termination points will themselves be contained
        in a supporting node.
        This dependency information can be inferred from
        the dependencies between links. For this reason,
        this item is not separately configurable. Hence no
        corresponding constraint needs to be articulated.
```


encoding [RFC7951]. The example instantiates ietf-network-topology (and ietf-network, which ietf-network-topology augments) for the topology that is depicted in the following diagram. There are three nodes, D1, D2, and D3. D1 has three termination points, 1-0-1, 1-2-1, and 1-3-1. D2 has three termination points as well, 2-1-1, 2-0-1, and 2-3-1. D3 has two termination points, 3-1-1 and 3-2-1. In addition there are six links, two between each pair of nodes with one going in each direction.

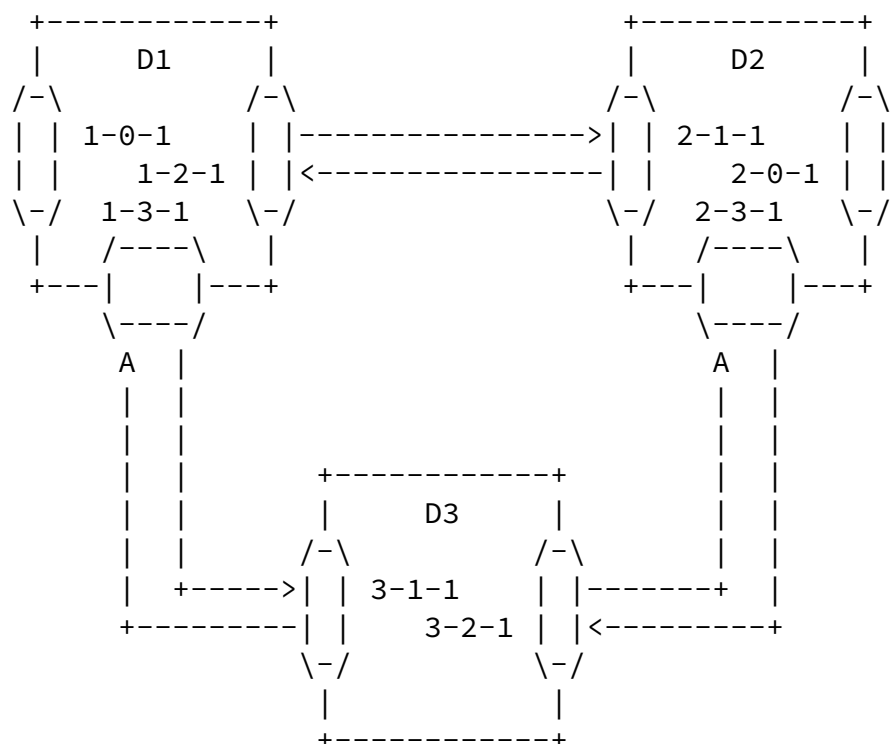


Figure 7: A network topology example

The corresponding instance data tree is depicted below:

```

{
  "ietf-network:networks": {
    "network": [
      {
        "network-types": {
        },
        "network-id": "otn-hc",
        "node": [
          {
            "node-id": "D1",
            "termination-point": [
              {
                "tp-id": "1-0-1"
              },
              {
                "tp-id": "1-2-1"
              },
              {
                "tp-id": "1-3-1"
              }
            ]
          }
        ]
      },

```

```

{
  "node-id": "D2",
  "termination-point": [
    {
      "tp-id": "2-0-1"
    },
    {
      "tp-id": "2-1-1"
    },
    {
      "tp-id": "2-3-1"
    }
  ]
},
{
  "node-id": "D3",
  "termination-point": [
    {
      "tp-id": "3-1-1"
    }
  ]
}

```

```

    },
    {
      "tp-id": "3-2-1"
    }
  ]
}
],
"ietf-network-topology:link": [
  {
    "link-id": "D1,1-2-1,D2,2-1-1",
    "destination": {
      "source-node": "D1",
      "source-tp": "1-2-1"
    }
    "destination": {
      "dest-node": "D2",
      "dest-tp": "2-1-1"
    }
  },
  {
    "link-id": "D2,2-1-1,D1,1-2-1",
    "destination": {
      "source-node": "D2",
      "source-tp": "2-1-1"
    }
    "destination": {
      "dest-node": "D1",
      "dest-tp": "1-2-1"
    }
  }
]

```

```

  },
  {
    "link-id": "D1,1-3-1,D3,3-1-1",
    "destination": {
      "source-node": "D1",
      "source-tp": "1-3-1"
    }
    "destination": {
      "dest-node": "D3",
      "dest-tp": "3-1-1"
    }
  }
],

```



```

    {
      "link-id": "D3,3-1-1,D1,1-3-1",
      "destination": {
        "source-node": "D3",
        "source-tp": "3-1-1"
      }
      "destination": {
        "dest-node": "D1",
        "dest-tp": "1-3-1"
      }
    },
    {
      "link-id": "D2,2-3-1,D3,3-2-1",
      "destination": {
        "source-node": "D2",
        "source-tp": "2-3-1"
      }
      "destination": {
        "dest-node": "D3",
        "dest-tp": "3-2-1"
      }
    },
    {
      "link-id": "D3,3-2-1,D2,2-3-1",
      "destination": {
        "source-node": "D3",
        "source-tp": "3-2-1"
      }
      "destination": {
        "dest-node": "D2",
        "dest-tp": "2-3-1"
      }
    }
  ]
}
]

```

```

}
}

```

Figure 8: Instance data tree

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