NMOP
Internet-Draft
Intended status: Informational
Expires: 4 September 2024

O. Havel
B. Claise
Huawei
O. G. D. Dios
Telefonica
A. Elhassany
T. Graf
Swisscom
M. Boucadair
Orange

3 March 2024

Modeling the Digital Map based on RFC 8345: Sharing Experience and Perspectives
draft-havel-nmop-digital-map-00

Abstract

This document shares experience in modelling Digital Map based on the IETF RFC 8345 topology YANG modules and some of its augmentations. First, the concept of Digital Map is defined and its connection to the Digital Twin is explained. Next to Digital Map requirements and use cases, the document identifies a set of open issues encountered during the modelling phases, the missing features in RFC 8345, and some perspectives on how to address them.

Discussion Venues

This note is to be removed before publishing as an RFC.

Source for this draft and an issue tracker can be found at https://github.com/OlgaHuawei.

Status of This Memo

This Internet-Draft will expire on 4 September 2024.

Copyright Notice

Table of Contents

1. Introduction

[RFC8345] specifies a topology YANG model with many YANG augmentations for different technologies and service types. The modelling approach based upon [RFC8345] provides a standard IETF based API.

At the time of writing (2024), there are at least 59 YANG modules that are augmenting [RFC8345]; 58 IETF-authored modules and 1 BBF-authored module. 14 of these modules have maturity level of 'ratified', 17 of them have maturity level of 'adopted', 31 modules have maturity level of 'latest-approved', and 27 of these modules have maturity level of 'initial'. The up-to-date information can be found in the YANG Catalog [Catalog].

From the set of IETF RFCs and I-Ds (at different level of maturity), we designed a Digital Map Proof of concept (PoC), with the following objectives and functionalities:

* Can the central RFC 8345 YANG module be a good basis to model a Digital Map?

* How the different topology related IETF YANG modules fit (or not) together?

* Modelling of Digital Map entities, relationships, and rules how to build aggregated entities and relationships. Does the base model support key requirements that emerge for a specific layer?

* Modelling multiple underlay/overlay layers from Layer 2 to Layer 3 to customer service layer. To what extent it is easy to augment the base model to support new technologies?

* Can the base model be augmented for any new layer and technologies?

This memo documents an experience in the modeling aspects of the Digital Map, based on a PoC implementation, basically documenting the effort and the open issues encountered so far. During the PoC, we also identified a set of requirements and verified the PoC approach by demoing it iteratively.

Practically, we developed a PoC with a real lab, based on multi-vendor devices, with [RFC8345] as the base YANG module.
The PoC successfully modelled the following:

* Layer 2 network topology (used [RFC8944])

* Layer 3 network topology (used [RFC8346])

* OSPF routing topology (aligned with [I-D.ogondio-opsawg-ospf-topology])

* IS-IS routing topology (aligned with [I-D.ogondio-opsawg-isis-topology])

* BGP routing topology

* MPLS LDP

* MPLS Traffic Engineering (TE) tunnels

* SRv6 tunnels

* L3VPN service

1.1. Terminology

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.

The document uses the following terms

Digital Twin: Virtual instance of a physical system (twin) that is continually updated with the latter’s performance, maintenance and health status data throughout the physical system’s life cycle (as defined in Section 2.2 of [I-D.irtf-nmrg-network-digital-twin-arch]

Topology: Network topology defines how physical or logical nodes, links and interfaces are related and arranges. Service topology defines how service components (e.g., VPN instances, customer interfaces, and customer links) between customer sites are interrelated and arranged. There are at least 8 types of topologies: point to point, bus, ring, star, tree, mesh, hybrid and daisy chain. Topologies may be unidirectional or bidirectional (bus, some rings).

Topology layer: Defines a layer in the multilayer topology. A multilayer topology models relationships between different layers of connectivity, where each layer represents a connectivity aspect of the network and service that needs to be configured, controlled and monitored.

The layer can also represent what needs to be managed by a specific user, for example IGP layer can be of interest to the user troubleshooting the routing, while the optical layer may be of interest to the user managing the optical network.

Some topology layers may relate closely to OSI layers, like L1 topology for physical topology, Layer 2 for link topology and Layer 3 for IPv4 and IPv6 topologies.

Some topology layers represent the control aspects of Layer 3, like OSPF, IS-IS, or BGP.

The top layer represents the service view of the connectivity, that can differ for different types of services and for different providers/solutions.

Digital Map: Basis for the Digital Twin that provides a virtual instance of the topological information of the network. It provides the core multi-layer topology model and data for the Digital Twin and connects them to the other Digital Twin models and data.

Digital Map modelling: The set of principles, guidelines, and conventions to model the Digital Map using the IETF [RFC8345] approach. They cover the network types (layers and sublayers), entity types, entity roles (network, node, termination point or link), entity properties and relationship types between entities.

Digital Map model: Defines the core topological entities, their role in the network, core properties and relationships both inside each layer and between the layers.

It is the basic topological model that is linked to other functional parts of the Digital Twin and connects them all: configuration, maintenance, assurance (KPIs, status, health, symptoms, etc.), traffic engineering, different behaviors, simulation, emulation, mathematical abstractions, AI algorithms, etc.

Digital Map data: Consists of instances of network and service topologies at different layers. This includes instances of networks, nodes, links and termination points, topological relationships between nodes, links and termination points inside a network, relationships between instances belonging to different networks, links to functional data for the instances, including configuration, health, symptoms.
:The data can be historical, real-time, or future data for 'what-if' scenarios.

2. Digital Map and Digital Twin Relationship

2.1. Digital Twin

The network digital twin (referred to simply as Digital Twin) concepts and a reference architecture are proposed in the "Digital Twin Network: Concepts and Reference Architecture" [I-D.irtf-nmrg-network-digital-twin-arch]. That reference document defines the core elements of Digital Twin: Data, Models, Interfaces, and Mapping.

The Digital Twin, constructed based on the four core technology elements, is intended to analyze, diagnose, emulate, and control the physical network in its whole lifecycle with the help of optimization algorithms, management methods, and expert knowledge.

Also, that document states that a Digital Twin can be seen as an indispensable part of the overall network system and provides a general architecture involving the whole lifecycle of physical networks in the future, serving the application of innovative network technologies (e.g., network planning, construction, maintenance and optimization, improving the automation and intelligence level of the network).

2.2. Digital Map

Digital Map provides the core multi-layer topology model and data for the Digital Twin and connects them to the other Digital Twin models and data.

The Digital Map modelling defines the core topological entities (network, node, link, and interface), their role in the network, core properties, and relationships both inside each layer and between the layers.

The Digital Map model can be approached as a topological model that is linked to other functional parts of the Digital Twin and connects them all: configuration, maintenance, assurance (KPIs, status, health, symptoms), Traffic Engineering (TE), different behaviors and actions, simulation, emulation, mathematical abstractions, AI algorithms, etc.

The Digital Map data consists of virtual instances of network and service topologies at different layers.
The Digital Map provides the access to this data via standard APIs for both read and write operations (write operations for offline simulations), with query capabilities and links to other YANG modules (e.g., Service Assurance for Intent-based Networking (SAIN) [RFC9417], Service Attachement Points (SAPs) [RFC9408], Inventory [I-D.ietf-ivy-network-inventory-yang], and Assets [I-D.palmero-opsawg-dmlmo]) and non-YANG models.

2.3. Digital Map as a Prerequisite for Digital Twin

One of the important requirements for Digital Twin is to ease correlating all models and data to topological entities at different layers in the layered twin network. The Digital Map aims to provide a virtual instance of the topological information of the network, based on this Digital Map Model. *Building a Digital Map is prerequisite towards the Digital Twin.*

The Digital Map model/data provide this missing correlation between the topology models/data and all other models/data: KPIs, alarms, incidents, inventory (with UUIDs), configuration, traffic engineering, planning, simulation ("what-if"), emulations, actions, and behaviors.

Some of these models/data provide a device view, some provide a network or subnetwork view, while others focus more on the customer service perspective. All these views are needed for both inner and outer closed-loops.

It is debatable what is part of the Digital Map itself versus what are pointers from the Digital Map to some other sources of information. As an example, a Digital Map should not specifically include all information about the device inventory (product name, vendor, product series, embedded software, and hardware/software versions, as specified in Network Inventory (IVY) WG, for example. A pointer to another inventory system might be sufficient or support of means that ease the mapping between inventory and topology.

Similarly, Digital Map should not specifically contain incidents, configuration, data plane monitoring, or even assurance information, simply to name a few.

The following are sample Digital Twin use cases that require Digital Map:

* Generic inventory queries

* Service placement feasibility checks

* Service-> subservice -> resource

* Resource -> subservice -> service

* Intent/service assurance

* Service E2E and per-link KPIs on the Digital Map (delay, jitter, and loss)

* Capacity planning

* Network design

* Simulation

* Closed loop

Overall, the Digital Map is needed to break down data islands and have a Digital Twin for emulation and closed loop, which is a catalyst for autonomous networking.

3. The IETF Network Topology Approaches

3.1. IETF Network Topology

[RFC8345] provides a simple generic topological model. It defines the abstract /generic /base model for network and service topologies. It provides the mechanism to model networks and services as layered topologies with common relationships at the same layer and underlay/ overlay relationships between the layers.

[RFC8345] consists of two modules: 'ietf-network' and 'ietf-network-topology'. The 'ietf-network' module defines networks and nodes, while 'ietf-network-topology' module adds definitions for links and termination points.

The relationships inside the layer are containment/aggregation (a network has nodes, a network has links, a node has termination points), source (a link has one source termination point) and destination (a link has one destination termination point).

The relationships between the layers are modelled via supporting relationship:

* network A is supported by network B - this may model overlay/ underlay relationship

* nodes, links and termination points of network A are supported by nodes, links and termination points of network B.
  Overlay and underlay nodes, links and termination points must match underlay and overlay networks supporting it

3.2. IETF Network Topology TE

[RFC8795] defines a YANG model for representing, retrieving and manipulating traffic engineering (TE) topologies. This is a more complex model which augments [RFC8345] with TE topology information as follows:

* TE nodes, links, and termination points are defined using the core RFC8345 concepts

  - TE topology augments 'ietf-network' with topology identifier (provider, client and topology id), as well as other 'TE' information

  - TE node augments 'node' with 'te-node-id' and other 'TE' information

  - TE link augments 'link' with 'TE' information

- TE termination point augments termination point with 'te-tp-id' and 'TE' information

* Tunnel, tunnel termination point, local link connectivity, node connectivity matrix, and some supporting and underlay relationships are defined outside of the core RFC 8345 entities and relationships

4. Digital Map Requirements

<-- We discussed if requirements should be in a separate document. We would leave them in this document for now, later we can create a separate draft -->

The following are the core requirements for the Digital Map (note that some of them are supported by default by [RFC8345]):

1. Basic model with network, node, link, and interface entity types.

2. Layered Digital Map, from physical network (ideally optical, layer 2, layer 3) up to customer service and intent views.

3. Open and programmable Digital Map: This includes "read" operations to retrieve the view of the network, typically as NorthBound Interface (NBI) of Software Defined Networking (SDN) controllers or orchestrators. It also includes "write" operations, not for the ability to directly change the Digital Map data (e.g., changing the network or service parameters), but for offline simulations, also known as what-if scenarios. Running a "what-if" analysis requires the ability to take snapshots and to switch easily between them. Note that there is a need to distinguish between a change on the Digital Map for future simulation and a change that reflects the current reality of the network.

4. Standard based Digital Map Models and APIs, for multi-vendor support: Digital Map must provide the standard APIs that provide for read/write and queries. These APIs must also provide the capability to retrieve the links to external data/models.

5. Digital Map models and APIs must be common over different network domains (campus, core, data center, etc.)

6. Digital Map must provide semantics for layered network topologies and for linking external models/data.

7. Digital Map must provide inter-layer and between layer relationships.

8. Digital Map must be extensible with metadata.

9. Digital Map must be pluggable:

   * Must connect to other YANG modules for inventory, configuration, assurance, etc.

   * Given that no all involved components can be available using YANG, there is a need to connect digital map YANG model with other modelling mechanisms.

10. Digital Map must be optimized for graph traversal for paths. This means that only providing link nodes and source and sink relationships to termination-points may not be sufficient, we may need to have the direct relationship between the termination points or nodes.

4.1. Why RFC8345 is a Good Approach for Digital Map Modelling

The main reason for selecting RFC8345 for modelling is its simplicity and that is supports majority of the core requirements. The requirements [1-7] are automatically fulfilled with RFC8345 and extensions:

* Basic model with network, node, link and interface entity types

* Layered topology

* Open and programmable

* Standard, multi-vendor

* Multi-domain

* Semantics for layered topology

* Inter-layer and between-layer relationships

The requirements [6-7] for semantics for layered topology and relationships are partially fulfilled, there may be need for some additional semantics. Other core requirements [8-10] are not supported by RFC8345:

* Extensible with metadata

* Pluggable to other YANG modules and non-YANG data

* Optimized for graph traversal

In some cases, for [9] for pluggable to other YANG modules, the links are already done by augmenting 'ietf-network' and 'ietf-network-topology'. For others, we need to add some mechanisms to link the models and data.

4.2. Design Requirements

The following are design requirements for modelling the Digital Map:

1. Digital Map should contain only topological information. Digital Map is not required to contain all data required for all the management and use cases. However, it should be designed to support adequate pointers to other functional Digital Twin data and models to ease navigating in the overall system. For example:

* ACLs and Route Policies are not required to be supported in the Digital Map, they would be linked to Digital Map

* Dynamic paths may either be outside of the Digital Map or part of traffic engineering data/models

1. Digital Map entities should mainly contain properties used to identify topological entities at different layers, identify their roles, and topological relationships between them.

2. Digital Map should contain only topological relationships inside each layer or between the layers (underlay/overlay).

3. Provide capability for conditional retrieval of parts of Digital Map.

4. Must support geo-spatial, temporal, and historical data. The temporal and historical can be supported external to the Digital Map.

The following are the architectural requirements for the Digital Map:

1. Scale, performance, ease of integration

2. Initial discovery and dynamic (change only) synch with the physical network

5. Digital Map Modelling Experience

5.1. What Is Not in The Base Model?

Based on some shared experience, the following are listed as set of candidate extensions to [RFC8345] for Digital Map modelling and APIs:

* An alternate approach to model bidirectional links
* An alternate approach to multi-point connectivity
* Links between domains/networks
* A network decomposition into sub-networks
* Nodes, links, and termination points belonging to different networks
* Supporting relationships between different types of entities
* More network topology related semantic is needed

5.1.1. Bidirectional Links

One of the core characteristics of any network topology is the link directionality. While data flows are unidirectional, the bidirectional links are also common in networking. Examples are Ethernet cables, bidirectional SONET rings, socket connection to the server, etc. We also encounter requirements for simplified service layer topology, where we want to model link as bidirectional to be supported by unidirectional links at the lower layer.

[RFC8345] defines all links as unidirectional, it does not support bidirectional links. It was done intentionally to keep the model as simple as possible. While simplifying the model itself, the data and APIs are more complex for the cases with bidirectional links. In such cases, there is no need to increase the amount of instances / data transferred via API, stored in the database, or managed/ monitored by modeling unidirectional links.

This document suggests to model the bidirectional connections as pairs of unidirectional links.

[I-D.davis-opsawg-some-refinements-to-rfc8345] further elaborates on the need for bidirectional links in the network topologies and in the Digital Map. It also proposes how RFC8345 can be augmented to support missing components.

The following are the candidate approaches of how we can address this limitation:

* Use the current RFC8345 approach and implement it via multiple unidirectional links

* Don't change RFC8345, leave to different augmentations to solve the problem their own way

* Augment RFC8345 via basic approach as suggested in [I-D.davis-opsawg-some-refinements-to-rfc8345], fully backward compatible, appears simple and sufficient

* Augment RFC8345 via more sophisticated approach as suggested in [I-D.davis-opsawg-some-refinements-to-rfc8345], more complex but improves the integrity of the model, same instance structures produced

* Consider RFC8345bis

We suggest to start the work on RFC8345bis to provide the backward compatible way to support bidirectional links in the core topology model defined in ietf-network-topology. The starting point can be the basic approach from [I-D.davis-opsawg-some-refinements-to-rfc8345] that adds the following:

* direction-of-link with value BIDIRECTIONAL

* direction-of-point with value BIDIRECTIONAL

* list of termination points that could be used for bidirectional links as an alternative to having source and destination for unidirectional (although we can also implement it via the existing source and destination when direction BIDIRECTIONAL)

5.1.2. Multipoint Connectivity

The RFC8345 defines all links as point to point and unidirectional, it does not support multi-point links (hub and spoke, full mesh, complex). It was done intentionally to keep the model as simple as possible. The RFC suggests to model the multi-point networks via pseudo nodes.

Same as with unidirectionality, while simplifying the model itself, we are making data and APIs more complex for multi point topologies and we are increasing the amount of data transferred via API, stored in the database or managed/monitored.

One of the core characteristics of any network topology is its type and link cardinality. Any topology model should be able to model any topology type in a simple and explicit way, including point to multipoint, bus, ring, star, tree, mesh, hybrid and daisy chain. Any topology model should also be able to model any link cardinality in a simple and explicit way, including point to point, point to multipoint, multipoint to multipoint or hybrid.

By forcing the implementation of all topology types and all options for cardinality via unidirectional links and pseudo nodes, we are significantly increasing the complexity of APIs and data, but also lacking full topology semantics in the model. The model cannot be fully used to validate if topology instances are valid or not.

Note that the point to multipoint network type is also required in some cases at the OSPF layer.

[I-D.davis-opsawg-some-refinements-to-rfc8345] further elaborates on the need for multipoint connectivity in network topologies and in the Digital Map, in general. It also proposes how RFC8345 can be augmented to support these missing components.

The following are the candidate approaches of how we can address this limitation:

* Use the current RFC8345 and implement via virtual nodes

* Don’t change RFC8345, leave to different augmentations to solve the problem their own way (see how it is done in [RFC8795])

* Augment RFC8345 via basic approach as suggested in [I-D.davis-opsawg-some-refinements-to-rfc8345], fully backward compatible, appears simple and sufficient

* Augment RFC8345 via more sophisticated approach as suggested in [I-D.davis-opsawg-some-refinements-to-rfc8345], more complex but improves the integrity of the model, same instance structures produced

* Consider a RFC8345bis that provides backward compatible enhancement (similar to [I-D.davis-opsawg-some-refinements-to-rfc8345] approach without augmentations)

We suggest to start to work on RFC8345 bis to provide the backward compatible way to support multipoint connectivity in the core topology model defined in ietf-network-topology. The starting point can be the basic approach from

[I-D.davis-opsawg-some-refinements-to-rfc8345] that adds the following: * list of termination points for multipoint links as an alternative to having source and destination for point to point links via the existing source and destination * role-of-point * type-of-link

5.1.3. Links Between Networks

The RFC8345 defines all links as belonging to one network instance and having the source and destination as node and termination point only, not allowing to link to termination point of another network. This does not allow for links between networks in the case of multi-domains or partitioning. The only way would be to model each domain as node and have links between them.

In our IS-IS PoC (following [I-D.ogondio-opsawg-isis-topology]), we modelled IS-IS areas as networks and we needed to extend the capability to have links between different areas. We added network reference as well to the source / destination of the link. The [RFC8795] also augments links with external-domain info for the case of links that connect different domains.

The IS-IS topology [I-D.ogondio-opsawg-isis-topology] models Autonomous System (AS) or IS-IS domain as a network, and IS-IS areas as attributes of IS-IS nodes. The RFC8345 extension can be used to model IS-IS areas as networks and IS-IS links between L1-2 nodes as links between two different areas. This is not problem for OSPF, although the OSPF nodes can belong to multiple areas, the links can belong to only one area.

The following are some benefits of lifting the RFC 8345 limitations that all links must belong to only one network instance:

* IS-IS processes would be grouped in an area via the standard IETF RFC8345 network->node relationship.

* Applications and algorithms will consume topologies based on the generic entities and relationships, they will not need to understand the meaning of specific IS-IS attributes.

* The approach would be aligned with the IS-IS topology model and the IS-IS network view in manuals and documentation.

* Provide capability to link different IGP domains and links between them.

* Link between multiple networks/sub-networks is the common concept in network topology.

The following are the candidate approaches of how we can address this limitation:

* Use the current RFC8345 and implement domains via properties in augmentations

* Don't change RFC8345, leave to different augmentations to solve the problem their own way (see how it is done in [RFC8795])

* Augment RFC8345 by adding some simple solution (e.g. move [RFC8795] approach for multi-domain to RFC8345 digital map)

* Consider a RFC8345bis

We suggest to start to work on RFC8345 bis to provide the backward compatible way to support links between networks in the core topology model defined in ietf-network-topology. The starting point can be to evaluate the approach from [RFC8795] that adds the external domain reference to the link via the external network, node and tp reference.

5.1.4. Networks Part of Other Networks

RFC8345 does not model networks being part of other networks, therefore cannot model subnetworks and network partitioning. We encountered this problem with modelling IS-IS and OSPF domains and areas. The initial goal was to model AS/domain with multiple areas so that the Digital Map model contains information about how the AS is first split into different IGP domains and how each IGP domain is split into different areas. This is a common problem for both IS-IS and OSPF.

The following are the candidate approaches of how we can address this limitation:

* Leave it as it is in RFC8345, don't model AS and IS-IS/OSPF domain directly, they would be modelled via the underlying IP network and IS-IS/OSPF enabled routers. This could be achieved via supporting relationship to L3 network and L3 nodes

* Leave it as it is in RFC8345, leave to different augmentations to solve the problem their own way

* Leave it as it is in RFC8345, model AS, IGP domains and areas as networks and use supporting relationship to model the network topology design, with only areas having nodes. This does not describe the correct nature of the relationship, semantic is missing.

* Augment RFC8345 by adding some simple solution to support additional partitioning relationship between networks.

* Consider a RFC8345bis

We suggest to start to work on RFC8345 bis to provide the backward compatible way to support partitioning of networks in the core network model defined in ietf-network. The solution needs to add a part-of relation between different networks, where one network (e.g. OSPF Domain) can contain multiple networks (e.g. OSPF areas)

5.1.5. Nodes, tps and links in multiple networks

RFC8345 does not allow nodes and TPs to belong to multiple areas without splitting them into separate entities with separate keys. In OSPF case, we have nodes that can belong to different areas, but interfaces can only belong to one area. In the case of IS-IS, although all tutorial are stating that nodes can belong to one area only, the IETF, openconfig and vendor yang models and CLI allow IS-IS processes with all its interfaces to belong to multiple areas.

The following are the candidate approaches of how we can address this limitation:

* Use the current RFC8345 approach, this is not the problem for read but may be an issue for write for simulation as we would expect that the interface lists in different nodes and networks be the same without being able to validate.

* Augment RFC8345 to optionally allow nodes to be defined outside of network tree and enable reference as an alternative to the containment in the tree. This may be a bigger change to the network topology approach as it would have bigger impact on the topology tree. Nevertheless, it can be an optional approach so would be backward compatible for those augmentations that do not want to use it

* Consider RFC8345 bis

We suggest to work on RFC8345 bis to provide the simple backward compatible way to support both the current RFC8345 approach of creating multiple instances and the approach of sharing the instances. The solution needs further analysis as it has bigger impact on the topology tree than other enhancements.

5.1.6. Missing Supporting Relationships

RFC8345 defines supporting relationships only between the same type of entities. Networks can only be supported by networks, nodes can only be supported by nodes, termination points can only be supported by terminations points and links can only be supported by links.

During the PoC, we encountered the need to have TP supported by node and node supported by Network. The RFC8795 also adds additional underlay relationship between node and topology and link and topology, but via a new underlay topology and not via the core supporting relationship.

The following are the candidate approaches to address this limitation:

* Use the current RFC8345 approach, leave to different augmentations to solve the problem their own way (see how it is done in [RFC8795])

* Augment RFC8345 by adding some simple solution (e.g. move [RFC8795] approach to RFC8345)

* Consider RFC8345 bis that provides backward compatible enhancement (e.g. via [RFC8795] basic approach)

We suggest to work on RFC8345 bis to provide the backward compatible way to add the missing supporting relationships: tp->supporting->node, node->supporting->network.

5.1.7. Missing Topology Semantics

We already mentioned that some semantic is missing from the RFC8345 topology model, like bidirectional and multi-point. The following is also missing from the model:

* Relationship Properties. The supporting relationship could have additional attributes that give more information about the supporting relationship. That way we could use it for aggregation, underlay with primary/backup, load balancing, hop, sequence, etc.

* Termination point roles. We are missing semantics for the common topology roles: primary, backup, hub, spoke

* Layers / Sublayers. We need further analysis to determine in network types are sufficient to support all scenarios for layers/ sublayers. The network types are more related to technologies so

in the case that the same technology is used at different layers, we may need some additional information in the model. For further study.

* Tunnels and paths. We modelled tunnels and paths via [RFC8345] but we lost some semantics that is in [RFC8795] .

* Supporting or underlay. We modelled all underlay relationships via supporting, further analysis is needed to determine pros and cons of this approach versus RFC8795 approach of using underlay topology.

The following are the candidate approaches to address this limitation:

* Use the current RFC8345 approach, leave to different augmentations to solve the problem their own way (see how it is done in [RFC8795])

* Augment RFC8345 by adding some simple solution (e.g. move [RFC8795] approach to RFC8345)

* Consider RFC8345bis

We suggest to work on RFC8345 bis to provide the backward compatible way to add the minimum semantics that the community agrees is required for the core topology. We need to further investigate the [RFC8795] approach and evaluate if some parts could be moved to RFC8345.

5.2. Open Issues (for Further Analysis or Resolved)

The following are the open issues that need further analysis or have been resolved:

* Do we need separation of L2 and L3 topologies?

  During the PoC we encountered different solutions with separate set of requirements. In one solution, the L2 and L3 topology were the same with separate set of attributes, while in another solution we had difference in L2 and L3 topology (e.g. Links Aggregation, Switches and Routers).

  The RFC8944 defines L2 topology and RFC8346 defines the L3 topology. They allow to have either one or two instances of this topology.

The decision if we need separate network instances for L2 and L3 topologies may be based on specific network topology and provider's preferences.

Resolved: the RFC8345 is flexible and it can support both the same network instance with L2 + L3 augmentations or separate network instances with supporting relationship between. The operator should decide what option is needed for their solution.

* Do we need sublayers as well? Layers versus sublayers versus layered instances?

  Resolved: Layers/sublayers could be implemented via multiple network types. The new data nodes for layer are present only when the network type for the layer is present. The new data nodes for the sublayer are present when the network types for both layer and sublayer are present. The solution could also enable either single or multiple instances, like in the previous point.

* Same technology at service versus underlay? BGP per VPN vs common BGP shared between multiple VPNs. Different layers, same model, relationship define the layer.

  Further analysis is needed.

* There are potential circular dependencies in layering. For example routing can be underlay for tunnels, but tunnel interface can also be in the routing table.

* Further analysis is needed.

6. Digital Map Modeling Guidelines

6.1. Guidelines for Generic Digital Map Extensions

Generic Digital Map extensions are the RFC8345 extensions required for all technologies and layers in the Digital Map. We already discussed some options for individual limitations in the previous sections, here is the summary:

1. Use the current RFC8345 approach, leave to different augmentations to solve th
e problem their own way

2. Augment RFC8345 network, node, link and termination point for any changes needed from a new digital map module

```
module: dm-network-topology
        augment /nw:networks/nw:network:
                .... additions
        augment /nw:networks/nw:network/nw:node:
                .... additions
        augment /nw:networks/nw:network/nt:link:
                .... additions
        augment /nw:networks/nw:network/nw:node/nt:termination-point:
                .... additions
```

// This can be a separate draft with describing pros and cons of
// different approaches and yang model proposal. Add reference to
// this draft when submitted

3. Make backward compatible updates to RFC8345, work on RFC8345 bis

The following are some important guidelines mentioned in the RFC8345 that should be taken into account when suggesting the approach:

* "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 comes 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"

* 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."

Our recommendation on how to extend RFC8345 for Digital Map is to stay in spirit of RFC8345 and augment with non-topological info only. Reuse network, node, link, tp for all topological entities, reuse supporting for layering and add new properties/attributes and references to other modules Therefore, we suggest to work on RFC8345 bis to provide the backward compatible way to address all identified limitations.

The alternative of having the core topology augmentations in either TE modules or technology specific modules is not generic enough and is not in the spirit of having the core topology model to model topology in the consistent manner between different technologies and TE and non-TE topologies.

6.2. Guidelines for New Technologies/Layers Extensions

There are already drafts that support augmentation for specific technologies. These drafts augment network, node, termination point and link, but also add different topological entities inside augmentations. For example, we have examples like this:

```
 module: new-module
         augment /nw:networks/nw:network/nw:network-types:
       +--rw new-topology!
                 augment /nw:networks/nw:network:
                                 ....
                 augment /nw:networks/nw:network/nw:node:
                         .... adding list of tps of other type
                                  (e.g. tunnel TPs in TE draft)
                         ... adding new supporting relationship
                                  supporting-tunnel-termination-point
                                  (te draft)
                 augment /nw:networks/nw:network/nt:link:
                                 .... adding tunnels (te draft)
                 augment /nw:networks/nw:network/nw:node/
                                               nt:termination-point:
                                 ....
```

There is a need to agree some guidelines for augmenting IETF network topology, so that additional topological information is not added in the custom way. There is also need to categorize the current augmentations and the impact of RFC 8345 bis based on what has been added for different technologies:

* new properties/attributes (e.g. ietf-l2-topology, ietf-l3-unicast-topology, ietf-isis-topology)

* new events (e.g. ietf-l2-topology)

* new topological entities (e.g. ietf-te-topology, ietf-dc-fabric-topology)

* new topological relations (e.g. ietf-te-topology)

* type reuse (e.g. ietf-dots-telemetry, ietf-dc-fabric-types, ietf-dc-fabric-topology)

<-- This can be a separate draft. Guidelines with examples? Add reference to this draft when submitted -->

6.3. Guidelines for Digital Maps Connectiont to Other Components

Digital Map must be pluggable:

* We must connect to other YANG modules for inventory, configuration, assurance, etc

* Not everything can be in YANG, we need to connect digital map YANG model with other modelling mechanisms, both southbound, northbound and internally

Also, there are already some modules that connect network topology to other YANG modules. We will investigate different approaches and propose the best practices. The following are some existing approaches proposed in IETF:

* How to connect network topology to interface [I-D.draft-ietf-ccamp-if-ref-topo-yang]

* How to connect network topology to hardware inventory [I-D.ietf-ccamp-network-inventory-yang]

* How to connect network topology to ivy inventory [I-D.draft-wzwb-ivy-network-inventory-topology]

* How to connect network topology to performance monitoring [RFC9375]

6.3.1. How to connect YANG models with other modelling mechanisms

There is need to connect YANG network topology to models and data outside of YANG, for example BMP, IPFIX, logs, etc.

6.4. Digital Map APIs

This will include hierarchical APIs for cross-domain figure, IETF YANG Based API (read and write, change subscription and notify) and Query API

6.5. Digital Map Knowledge

The following knowledge was needed to build Digital Map:

* Abstract IETF Entities and Relationships as in [RFC8345]

* [RFC8345] Augmentations for a)Layers/sublayers b)Entities (services and subservices), c)Properties

* Rules for aggregating entities

* Rules for instantiating relationships (inter-layer and intra-layer)

* Mapping from devices and controllers

What can be achieved with existing RFC8345 YANG:

* Entities (base class IETF Network, IETF Node, IETF Link, IETF TP)

* Properties

* Relationships

Next steps

* How to support temporal

* How to support spacial

* How to support historical

7. Related IETF Activities

7.1. Network Topology

Interestingly, we could not find any network topology definition in IETF RFCs (not even in [RFC8345]) or drafts. However, it's mentioned in multiple documents. As an example, in Overview and Principles of Internet Traffic Engineering [I-D.ietf-teas-rfc3272bis], which mentioned:

To conduct performance studies and to support planning of existing and future networks, a routing analysis may be performed to determine the paths the routing protocols will choose for various traffic demands, and to ascertain the utilization of network resources as traffic is routed through the network. Routing analysis captures the selection of paths through the network, the assignment of traffic across multiple feasible routes, and the multiplexing of IP traffic over traffic trunks (if such constructs exist) and over the underlying network infrastructure. A model of network topology is necessary to perform routing analysis. A network topology model may be extracted from:

* Network architecture documents

* Network designs

* Information contained in router configuration files

* Routing databases such as the link state database of an interior gateway protocol (IGP)

* Routing tables

* Automated tools that discover and collate network topology information.

Topology information may also be derived from servers that monitor network state, and from servers that perform provisioning functions.

7.2. Core Digital Map Components

The following standards are core for the Digital Map.

* IETF network model and network topology model [RFC8345]

* A YANG grouping for geographic location [RFC9179]

* IETF modules that augment [RFC8345] for different technologies:

* - A YANG data model for Traffic Engineering (TE) Topologies [RFC8795]

* - A YANG data model for Layer 2 network topologies [RFC8944]

* - A YANG data model for OSFP topology [I-D.ogondio-opsawg-ospf-topology]

* - A YANG data model for IS-IS topology [I-D.ogondio-opsawg-isis-topology]

7.3. Additional Digital Map Components

The Digital Map may need to link to the following models, some are already augmenting [RFC8345], we need further investigation for each of these items:

* Service Access Point (SAP) [RFC9408], augments 'ietf-network' data model [RFC8345] by adding the SAP.

* SAIN [RFC9417] and [RFC9418]

* Network Inventory Model [I-D.draft-ietf-ivy-network-inventory-yang] is the latest inventory model proposed by ivy, focusing on physical and virtual inventory. Logical inventory is currently outside of the scope. It does not augment RFC8345 like the two drafts that it evolved from [I-D.ietf-ccamp-network-inventory-yang] and [I-D.wzwb-opsawg-network-inventory-management]. The [I-D.draft-wzwb-ivy-network-inventory-topology] correlates the network inventory with the general topology via RFC8345 augmentations that reference inventory.

* Data Model for Lifecycle Management and Operations [I-D.palmero-opsawg-dmlmo]

* KPIs: delay, jitter, loss

* Attachment Circuits (ACs) [I-D.boro-opsawg-ntw-attachment-circuit] and [I-D.boro-opsawg-teas-attachment-circuit]

* Configuration: L2SM [RFC8466], L3SM [RFC8299], L2NM [RFC9291], L3NM [RFC9182]

* Incident Management for Network Services [I-D.feng-opsawg-incident-management]

7.4. Network Inventory (IVY) Proposed Working

The charter of the Network Inventory (IVY) IETF Working Group (WG) can be found at https://datatracker.ietf.org/doc/charter-ietf-ivy/. Understanding how the two efforts complement each other is important.

The IVY effort focuses on the network inventory (as the charter says, "including a variety of information such as product name, vendor, product series, embedded software, and hardware/software versions").

The network inventory is probably the first use cases for the digital map. Therefore, it is important to have a consistent view of what a network node is. While a Digital Map must include a pointer to the hardware and software inventory information, we don't consider that all the inventory information is actually part of the Digital Map. It must also be noted that the set of use cases for the Digital Map is wider than just the network inventory.

The IVY charter also says that, "The Working Group will consider existing IETF work, including RFC 8348 and RFC 8345.". In this document, RFC 8345 is considered as the base YANG module, therefore, there is clearly common ground with the work of the ivy working group. This document goes beyond RFC 8345 to evaluate whether that RFC, along with all the augmented YANG modules, would be a good fit for all the Digital Map requirements.

Additionally, the IVY charter says, "The WG will also identify a set of requirements and guidelines to ensure consistency across models related to inventory." While the IVY requirements and guidelines focus on inventory, this document looks at the full set of requirements, guidelines, and building blocks for all the Digital Map use cases. The inventory use case does not cover that full set, and other building blocks will be required: for example, to support point-to-multipoint connectivity

Thus, this Digital Map modelling effort is complementary to the inventory work in IVY. It has a broader outlook covering all Digital Map use case requirements, and will correlate with the existing IETF models, e.g., topology, service attachment points (SAP), etc.

8. Conclusions

Digital Map Modelling and Data are basis for the Digital Twin. During our PoC we have proven that Digital Map can be modelled using [RFC8345]. Nevertheless, we proposed some extensions/augmentations to [RFC8345] to support Digital Maps. There must be some constraints in regards to how to augment the core Digital Map model for different Layers and Technologies in order to support the approach recommended in RFC8345 and implemented in our PoC. All entities must augment IETF node, IETF network, IETF link or IETF Termination Point and augmentation can only include new properties, events, references.

We suggest to start the work on RFC8345 bis to provide the backward compatible way to support the following basic topological features:

* bidirectional links

* multipoint connectivity

* cross-domain links via links between networks

* multi-domain via network partitioning

* shared topological entities between different domains

* additional supporting relations

* additional semantics required for core topologies

9. Security Considerations

This section uses the template described in Section 3.7 of [I-D.ietf-netmod-rfc8407bis].

The YANG modules cited in this document define a schema for data that is 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 [RFC8446].

The Network Configuration Access Control Model (NACM) {{!RFC8341] 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 specifications that define these modules call out both sensitive and vulnerable writable and readable data nodes. These considerations are not reiterated here.

10. IANA Considerations

This document has no actions for IANA.

11. References

11.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/rfc/rfc2119>.

[RFC6241] Enns, R., Ed., Bjorklund, M., Ed., Schoenwaelder, J., Ed., and A. Bierman, Ed., "Network Configuration Protocol (NETCONF)", RFC 6241, DOI 10.17487/RFC6241, June 2011, <https://www.rfc-editor.org/rfc/rfc6241>.

[RFC6242] Wasserman, M., "Using the NETCONF Protocol over Secure Shell (SSH)", RFC 6242, DOI 10.17487/RFC6242, June 2011, <https://www.rfc-editor.org/rfc/rfc6242>.

[RFC8040] Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", RFC 8040, DOI 10.17487/RFC8040, January 2017, <https://www.rfc-editor.org/rfc/rfc8040>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/rfc/rfc8174>.

[RFC8345] Clemm, A., Medved, J., Varga, R., Bahadur, N., Ananthakrishnan, H., and X. Liu, "A YANG Data Model for Network Topologies", RFC 8345, DOI 10.17487/RFC8345, March 2018, <https://www.rfc-editor.org/rfc/rfc8345>.

[RFC8346] Clemm, A., Medved, J., Varga, R., Liu, X., Ananthakrishnan, H., and N. Bahadur, "A YANG Data Model for Layer 3 Topologies", RFC 8346, DOI 10.17487/RFC8346, March 2018, <https://www.rfc-editor.org/rfc/rfc8346>.

[RFC8446] Rescorla, E., "The Transport Layer Security (TLS) Protocol Version 1.3", RFC 8446, DOI 10.17487/RFC8446, August 2018, <https://www.rfc-editor.org/rfc/rfc8446>.

[RFC8795] Liu, X., Bryskin, I., Beeram, V., Saad, T., Shah, H., and O. Gonzalez de Dios, "YANG Data Model for Traffic Engineering (TE) Topologies", RFC 8795, DOI 10.17487/RFC8795, August 2020, <https://www.rfc-editor.org/rfc/rfc8795>.

[RFC8944] Dong, J., Wei, X., Wu, Q., Boucadair, M., and A. Liu, "A YANG Data Model for Layer 2 Network Topologies", RFC 8944, DOI 10.17487/RFC8944, November 2020, <https://www.rfc-editor.org/rfc/rfc8944>.

11.2. Informative References

[Catalog] YANG Catalog, "YANG Impact Analysis", n.d., <https://yangcatalog.org/yang-search/impact_analysis/ietf-network-topology@2018-02-26>.

[I-D.boro-opsawg-ntw-attachment-circuit] Boucadair, M., Roberts, R., de Dios, O. G., Barguil, S., and B. Wu, "A Network YANG Data Model for Attachment Circuits", Work in Progress, Internet-Draft, draft-boro-opsawg-ntw-attachment-circuit-03, 5 September 2023, <https://datatracker.ietf.org/doc/html/draft-boro-opsawg-ntw-attachment-circuit-03>.

[I-D.boro-opsawg-teas-attachment-circuit]
Boucadair, M., Roberts, R., de Dios, O. G., Barguil, S., and B. Wu, "YANG Data Models for 'Attachment Circuits'-as-a-Service (ACaaS)", Work in Progress, Internet-Draft, draft-boro-opsawg-teas-attachment-circuit-07, 10 July 2023, <https://datatracker.ietf.org/doc/html/draft-boro-opsawg-teas-attachment-circuit-07>.

[I-D.davis-opsawg-some-refinements-to-rfc8345]
Davis, N., Havel, O., and B. Claise, "Some Refinements to Network Topologies (RFC8345)", Work in Progress, Internet-Draft, draft-davis-opsawg-some-refinements-to-rfc8345-01, 10 January 2024, <https://datatracker.ietf.org/doc/html/draft-davis-opsawg-some-refinements-to-rfc8345-01>.

[I-D.draft-ietf-ccamp-if-ref-topo-yang]
Ahlberg, J., Mansfield, S., Ye, M., Busi, I., Li, X., and D. Spreafico, "A YANG Data Model for Interface Reference Topology", Work in Progress, Internet-Draft, draft-ietf-ccamp-if-ref-topo-yang-01, 18 October 2023, <https://datatracker.ietf.org/doc/html/draft-ietf-ccamp-if-ref-topo-yang-01>.

[I-D.draft-ietf-ivy-network-inventory-yang]
Yu, C., Belotti, S., Bouquier, J., Peruzzini, F., and P. Bedard, "A YANG Data Model for Network Inventory", Work in Progress, Internet-Draft, draft-ietf-ivy-network-inventory-yang-00, 5 December 2023, <https://datatracker.ietf.org/doc/html/draft-ietf-ivy-network-inventory-yang-00>.

[I-D.draft-wzwb-ivy-network-inventory-topology]
Wu, B., Zhou, C., Wu, Q., and M. Boucadair, "A Network Inventory Topology Model", Work in Progress, Internet-Draft, draft-wzwb-ivy-network-inventory-topology-00, 18 October 2023, <https://datatracker.ietf.org/doc/html/draft-wzwb-ivy-network-inventory-topology-00>.

[I-D.feng-opsawg-incident-management]
Feng, C., Hu, T., Contreras, L. M., Graf, T., Wu, Q., Yu, C., and N. Davis, "Incident Management for Network Services", Work in Progress, Internet-Draft, draft-feng-opsawg-incident-management-04, 30 January 2024, <https://datatracker.ietf.org/doc/html/draft-feng-opsawg-incident-management-04>.

[I-D.ietf-ccamp-network-inventory-yang]
Yu, C., Belotti, S., Bouquier, J., Peruzzini, F., and P. Bedard, "A YANG Data Model for Network Hardware Inventory", Work in Progress, Internet-Draft, draft-ietf-ccamp-network-inventory-yang-02, 9 July 2023, <https://datatracker.ietf.org/doc/html/draft-ietf-ccamp-network-inventory-yang-02>.

[I-D.ietf-ivy-network-inventory-yang]
Yu, C., Belotti, S., Bouquier, J., Peruzzini, F., and P. Bedard, "A YANG Data Model for Network Inventory", Work in Progress, Internet-Draft, draft-ietf-ivy-network-inventory-yang-00, 5 December 2023, <https://datatracker.ietf.org/doc/html/draft-ietf-ivy-network-inventory-yang-00>.

[I-D.ietf-netmod-rfc8407bis]
Bierman, A., Boucadair, M., and Q. Wu, "Guidelines for Authors and Reviewers of Documents Containing YANG Data Models", Work in Progress, Internet-Draft, draft-ietf-netmod-rfc8407bis-09, 28 February 2024, <https://datatracker.ietf.org/doc/html/draft-ietf-netmod-rfc8407bis-09>.

[I-D.ietf-teas-rfc3272bis]
Farrel, A., "Overview and Principles of Internet Traffic Engineering", Work in Progress, Internet-Draft, draft-ietf-teas-rfc3272bis-27, 12 August 2023, <https://datatracker.ietf.org/doc/html/draft-ietf-teas-rfc3272bis-27>.

[I-D.irtf-nmrg-network-digital-twin-arch]
Zhou, C., Yang, H., Duan, X., Lopez, D., Pastor, A., Wu, Q., Boucadair, M., and C. Jacquenet, "Digital Twin Network: Concepts and Reference Architecture", Work in Progress, Internet-Draft, draft-irtf-nmrg-network-digital-twin-arch-04, 23 October 2023, <https://datatracker.ietf.org/doc/html/draft-irtf-nmrg-network-digital-twin-arch-04>.

[I-D.ogondio-opsawg-isis-topology]
de Dios, O. G., Barguil, S., Lopez, V., Ceccarelli, D., and B. Claise, "A YANG Data Model for Intermediate System to intermediate System (IS-IS) Topology", Work in Progress, Internet-Draft, draft-ogondio-opsawg-isis-topology-01, 23 October 2023, <https://datatracker.ietf.org/doc/html/draft-ogondio-opsawg-isis-topology-01>.

[I-D.ogondio-opsawg-ospf-topology]
de Dios, O. G., Barguil, S., and V. Lopez, "A YANG Data Model for Open Shortest Path First (OSPF) Topology", Work in Progress, Internet-Draft, draft-ogondio-opsawg-ospf-topology-01, 23 October 2023, <https://datatracker.ietf.org/doc/html/draft-ogondio-opsawg-ospf-topology-01>.

[I-D.palmero-opsawg-dmlmo]
Palmero, M., Brockners, F., Kumar, S., Bhandari, S., Cardona, C., and D. Lopez, "Data Model for Lifecycle Management and Operations", Work in Progress, Internet-Draft, draft-palmero-opsawg-dmlmo-10, 7 July 2023, <https://datatracker.ietf.org/doc/html/draft-palmero-opsawg-dmlmo-10>.

[I-D.wzwb-opsawg-network-inventory-management]
Wu, B., Zhou, C., Wu, Q., and M. Boucadair, "A YANG Network Data Model of Network Inventory", Work in Progress, Internet-Draft, draft-wzwb-opsawg-network-inventory-management-04, 19 October 2023, <https://datatracker.ietf.org/doc/html/draft-wzwb-opsawg-network-inventory-management-04>.

[RFC8299] Wu, Q., Ed., Litkowski, S., Tomotaki, L., and K. Ogaki, "YANG Data Model for L3VPN Service Delivery", RFC 8299, DOI 10.17487/RFC8299, January 2018, <https://www.rfc-editor.org/rfc/rfc8299>.

[RFC8466] Wen, B., Fioccola, G., Ed., Xie, C., and L. Jalil, "A YANG Data Model for Layer 2 Virtual Private Network (L2VPN) Service Delivery", RFC 8466, DOI 10.17487/RFC8466, October 2018, <https://www.rfc-editor.org/rfc/rfc8466>.

[RFC9179] Hopps, C., "A YANG Grouping for Geographic Locations", RFC 9179, DOI 10.17487/RFC9179, February 2022, <https://www.rfc-editor.org/rfc/rfc9179>.

[RFC9182] Barguil, S., Gonzalez de Dios, O., Ed., Boucadair, M., Ed., Munoz, L., and A. Aguado, "A YANG Network Data Model for Layer 3 VPNs", RFC 9182, DOI 10.17487/RFC9182, February 2022, <https://www.rfc-editor.org/rfc/rfc9182>.

[RFC9291] Boucadair, M., Ed., Gonzalez de Dios, O., Ed., Barguil, S., and L. Munoz, "A YANG Network Data Model for Layer 2 VPNs", RFC 9291, DOI 10.17487/RFC9291, September 2022, <https://www.rfc-editor.org/rfc/rfc9291>.

[RFC9375] Wu, B., Ed., Wu, Q., Ed., Boucadair, M., Ed., Gonzalez de Dios, O., and B. Wen, "A YANG Data Model for Network and VPN Service Performance Monitoring", RFC 9375, DOI 10.17487/RFC9375, April 2023, <https://www.rfc-editor.org/rfc/rfc9375>.

[RFC9408] Boucadair, M., Ed., Gonzalez de Dios, O., Barguil, S., Wu, Q., and V. Lopez, "A YANG Network Data Model for Service Attachment Points (SAPs)", RFC 9408, DOI 10.17487/RFC9408, June 2023, <https://www.rfc-editor.org/rfc/rfc9408>.

[RFC9417] Claise, B., Quilbeuf, J., Lopez, D., Voyer, D., and T. Arumugam, "Service Assurance for Intent-Based Networking Architecture", RFC 9417, DOI 10.17487/RFC9417, July 2023, <https://www.rfc-editor.org/rfc/rfc9417>.

[RFC9418] Claise, B., Quilbeuf, J., Lucente, P., Fasano, P., and T. Arumugam, "A YANG Data Model for Service Assurance", RFC 9418, DOI 10.17487/RFC9418, July 2023, <https://www.rfc-editor.org/rfc/rfc9418>.

Acknowledgments

Thanks to xx for their reviews and comments.

Contributors

Nigel Davis
Ciena
Email: ndavis@ciena.com

Authors' Addresses

Olga Havel
Huawei
Email: olga.havel@huawei.com

Benoit Claise
Huawei
Email: benoit.claise@huawei.com

Oscar González de Dios
Telefonica
Email: oscar.gonzalezdedios@telefonica.com

Ahmed Elhassany
Swisscom
Email: Ahmed.Elhassany@swisscom.com

Thomas Graf
Swisscom
Email: thomas.graf@swisscom.com

Mohamed Boucadair
Orange
Email: mohamed.boucadair@orange.com

nmop
Internet-Draft
Intended status: Standards Track
Expires: 5 September 2024

O. G. D. Dios
Telefonica
S. B. Giraldo
V. Lopez
Nokia
D. Ceccarelli
Cisco
B. Claise
Huawei

4 March 2024

A YANG Data Model for Intermediate System to intermediate System (IS-IS) Topology

draft-ogondio-nmop-isis-topology-00

Abstract

This document defines a YANG data model for representing an abstracted view of a network topology that contains Intermediate System to Intermediate System (IS-IS). This document augments the 'ietf-network' data model by adding IS-IS concepts and explains how the data model can be used to represent the IS-IS topology.

The YANG data model defined in this document conforms to the Network Management Datastore Architecture (NMDA).

Status of This Memo

Copyright Notice

Table of Contents

1. Introduction

Network operators perform the capacity planning for their networks and run regular what-if scenarios analysis based on representations of the real network. Those what-if analysis and capacity planning processes require, among other information, a topological view (domains, nodes, links, network interconnection) of the deployed network.

This document defines a YANG data model representing an abstracted view of a network topology containing Intermediate System to Intermediate System (IS-IS). It covers the topology of IP/MPLS networks running IS-IS as Interior Gateway Protocol (IGP) protocol. The proposed YANG model augments the "A YANG Data Model for Network Topologies" [RFC8345] and "A YANG Data Model for Layer 3 Topologies" [RFC8346] by adding IS-IS concepts. It is worth to highlight that the Yang model can also be used together with [RFC8795] and [I-D.draft-ietf-teas-yang-l3-te-topo] when Traffic engineering characteristics are required in the topological view.

This YANG data model can be used to export the IS-IS related topology directly from a network controller to Operation Support System (OSS) tools or to a higher level controller.

Note that the YANG model is in this document strictly adheres to the concepts (and the YANG module) in "A YANG Data Model for Network Topologies" [RFC8345] and"A YANG Data Model for Layer 3 Topologies" [RFC8346]. While investigating the IS-IS topology, some limitations have discovered in [RFC8345], regarding how the digital map can be represented. Those limitations (and potential improvements) are covered in [I-D.draft-havel-opsawg-digital-map].

This document explains the scope and purpose of the IS-IS topology model and how the topology and service models fit together. The YANG data model defined in this document conforms to the Network Management Datastore Architecture [RFC8342].

1.1. Terminology and Notations

This document assumes that the reader is familiar with IS-IS and the contents of [RFC8345]. The document uses terms from those documents.

The terminology for describing YANG data models is found in [RFC7950], [RFC8795] and [RFC8346].

The term Digital Twin, Digital Map, Digital Map Modelling, Digital Map Model, Digital Map Data, and Topology are specified in [I-D.draft-havel-opsawg-digital-map].

1.2. Requirements Language

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 [RFC2119], [RFC8174] when, and only when, they appear in all capitals, as shown here.

1.3. Tree Diagram

Authors include a simplified graphical representation of the data model specified in Section 5 of this document. The meaning of the symbols in these diagrams is defined in [RFC8340].

1.4. Prefix in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the corresponding YANG imported modules, as shown in the following table.

Prefix	Yang Module	Reference
isisnt	ietf-l3-isis-topology	RFCXXX
yang	ietf-yang-types	[RFC6991]

Table 1: Prefixes and corresponding YANG modules

RFC Editor Note: Please replace XXXX with the RFC number assigned to this document. Please remove this note.

2. Use Cases

This information is required in the IP/MPLS planning process to properly assess the required network resources to meet the traffic demands in normal and failure scenarios. Network operators perform the capacity planning for their networks and run regular what-if scenarios analysis based on representations of the real network. Those what-if analysis and capacity planning processes require, among other information, a topological view (domains, nodes, links, network interconnection) of the deployed network.

The standardization of an abstracted view of the IS-IS topology model as NorthBound Interface (NBI) of Software Defined Networking (SDN) controllers allows the unified query of the IS-IS topology in order to inject this information into third party tools covering specialized cases.

The IS-IS topological model should export enough IS-IS information to permit these tools to simulate the IP routing. By mapping the traffic demand, ideally at the IP flow level, to the topology, we can simulate the traffic growth, evaluating this way its effect on the routing and quality of service. That is, simulating how IP-level traffic demands would be forwarded, after IS-IS convergence is reached, and from there estimating, using appropriate mathematical models, related KPIs like the occupation in the links or end-to-end latencies.

In summary, the network-wide view of the IS-IS topology enables multiple use cases:

* Network design: verifying that the actual deployed IS-IS network conforms to the planned design.

* Capacity planning. Dimensioning or redesign of the IP infrastructure to satisfy target KPI metrics under existing or forecasted traffic demands.

* What-if analysis. Estimation of the network KPIs in modified network situations. For instance, failure situations, traffic anomaly situations, addition or deletion of new adjacencies, IGP weight reconfigurations, etc.

* Failure analysis. Systematic and massive test of the network under multiple simulated failure situations, evaluating the network fault tolerance properties, and using mathematical models to derive statistical network availability metrics.

2.1. Relationship with the IS-IS YANG Model

[RFC9130] specifies a YANG data model that can be used to configure and manage the IS-IS protocol on network elements. This data model covers the configuration of an IS-IS routing protocol instance, as well as the retrieval of IS-IS operational states. [RFC9130] is still expected to be used for individual network elements configuration and monitoring. On the other hand, the proposed YANG model in this document covers the abstracted view of the entire network topology containing IS-IS. As such, this model is aimed at being available via the NBI of an SDN controller.

2.2. Relationship with Digital Map

As described in [I-D.draft-havel-opsawg-digital-map], the Digital Map provides the core multi-layer topology model and data for the digital twin and connects them to the other digital twin models and data.

The Digital Map Modelling defines the core topological entities, their role in the network, core properties, and relationships both inside each layer and between the layers.

The Digital Map Model is a basic topological model that is linked to other functional parts of the digital twin and connects them all: configuration, maintenance, assurance (KPIs, status, health, symptoms), Traffic Engineering (TE), different behaviors and actions, simulation, emulation, mathematical abstractions, AI algorithms, etc.

As such the IGP topology of the Digital Map (in this case, IS-IS) is just one of the layers of the Digital Map, for specific user (the network operator in charge of the IGP) for specific IGP use cases as described before.

3. Use of IETF-Topology for Representing an IP/MPLS network domain

IP/MPLS networks can contain multiple domain IGP domains. We can define an IGP domain as the collection of nodes and links that participate in the same IGP process. The topology information of a domain can be structured according to ietf-network-topology data model [RFC8345]. For example, if BGP-LS [RFC9552] is used to collect the information, the nodes and links that are announced with the same combination of AS number / domain ID are considered to belong to the same domain.

If a node and/or layer termination point participates in more than one IGP, it will be present in multiple IGP domain networks. As the basic components, node/links/termination points [RFC8345], it is therefore possible to joint the different different IGP topologies from a digital map modeling point of view. The ietf-network instance MUST include the following properties to indicate it is a domain running an IGP instance:

A network-id that uniquely identifies such domain in the network. The "network-types" property should include the l3t:l3-unicast-topology, to indicate it is a network in which the nodes are capable of forwarding unicast packet. Also, this draft proposed to add a new property, "isis-topology", to indicate the topology being represented is running the IS-IS IGP process.

Also, should the topology include information such as bandwidth, delay information or color, it must include the "YANG Data Model for Traffic Engineering" [RFC8795] te-topology YANG data model. To include delay and bandwdith performance measurements , MUST include tet-pkt:te-packet under the previous property The supporting-network property can include the network-id of a base layer-3 network. The node property should include the list of nodes as described below. The ietf-network-topology:link MUST be present, with one link per each IP adjacency (one link for each direction of the adjancency).

4. YANG Data Model for IS-IS Topology

The abstract (base) network data model is defined in the "ietf-network" and "ietf-network-topology" modules of [RFC8345]. The L3 topology module is defined in the "ietf-l3-unicast-topology" module of [RFC8346]. The ietf-l3-isis-topology builds on the data models defined in [RFC8345] and [RFC8346], augmenting the nodes with IS-IS information.

There is a set of parameters and augmentations that are included at the node level. Each parameter and description are detailed following:

* Network-types: Its presence identifies the IS-IS topology type. Thus, the network type MUST be isis-topology.

* IS-IS timer attributes: Identifies the node timer attributes configured in the network element. They are LSP lifetime and the LSP refresh interval.

* IS-IS status: contains the IS-IS status attributes (level, area-address and neighbours).

The following figure is based on the Figure 1 from [RFC8346], where the example-ospf-topology is replaced with ietf-l3-isis-topology and where arrows show how the modules augment each other.

```
+-----------------------------+
|  +-----------------------+  |
|  |      ietf-network     |  |
|  +----------^------------+  |
|             |               |
|  +-----------------------+  |
|  | ietf-network-topology |  |
|  +----------+------------+  |
+-------------^---------------+
              |
              |
 +------------^-------------+
 | ietf-l3-unicast-topology |
 +------------^-------------+
              |
              |
  +-----------^-----------+
  | ietf-l3-isis-topology |
  +-----------------------+
```

Figure 1: IS-IS Topology module structure

There is a set of parameters and augmentations that are included at the network level.

* Network-types: Its presence identifies the IS-IS topology type. Thus, the network type MUST be isis-topology.

There is a set of parameters and augmentations that are included at the node level. Each parameter and description are detailed following:

* IS-IS node core attributes: contains the IS-IS core attributes (system-id, level, area-address).

* IS-IS timer attributes: Identifies the node timer attributes configured in the network element. They are LSP lifetime and the LSP refresh interval.

There is a set of parameters and augmentations that are included at the link level. Each parameter and description are detailed following:

* IS-IS link level. The level must be the same as the termination points at each end for Level 1 and Level 2 interfaces. There may be 2 links between the Level1-2 IS-IS interfaces, one for Level 1 adjacency and one for Level 2 adjacency.

* IS-IS link metric. Added on top of metric1 and metric2 of the l3-link-attributes

There is a set of parameters and augmentations are included at the termination point level. Each parameter is listed as follows:

* Interface-type: point-to point or broadcast

* Level. The level must be the same as for the node, except when node is Level 1-2 and the interfaces can only be Level 1 or Level 2.

* Passive mode

5. RFC8345 Limitations for the IS-IS Modeling

There are some limitations in the [RFC8345] that are explained in more detail in [I-D.draft-havel-opsawg-digital-map]. The current version of the ietf-l3-isis-topology module is based on the current version of [RFC8345]. The following will be addressed when [RFC8345] is extended to support the identified limitations:

* Both IS-IS domain and IS-IS areas could be modelled as networks

* The IS-IS Areas will be connected via IS-IS links

* IS-IS nodes could belong to multiple IS-IS networks

6. IS-IS Topology Tree Diagram

Figure 2 below shows the tree diagram of the YANG data model defined in module ietf-l3-isis-topology.yang (Figure 3).

```
module: ietf-l3-isis-topology

  augment /nw:networks/nw:network/nw:network-types:
    +--rw isis-topology!
  augment /nw:networks/nw:network/nw:node/l3t:l3-node-attributes:
    +--rw isis-timer-attributes
    |  +--rw lsp-mtu?        uint16
    |  +--rw lsp-lifetime?   uint16
    |  +--rw lsp-refresh?    rt-types:timer-value-seconds16 {lsp-refresh}?
    |  +--rw poi-tlv?        boolean {poi-tlv}?
    +--rw isis-node-attributes
       +--rw system-id?              ietf-isis:system-id
       +--rw level?                  ietf-isis:level
       +--rw area-address*           ietf-isis:area-address
       +--rw lsp-lifetime?           uint16
       +--rw lsp-refresh-interval?   uint16
  augment /nw:networks/nw:network/nt:link/l3t:l3-link-attributes:
    +--rw isis-link-attributes
       +--rw metric?   uint32
       +--rw level?    ietf-isis:level
  augment /nw:networks/nw:network/nw:node/nt:termination-point/l3t:l3-termination
-point-attributes:
    +--rw isis-termination-point-attributes
       +--rw interface-type?   ietf-isis:interface-type
       +--rw level?            ietf-isis:level
       +--rw is-passive?       boolean
```

Figure 2: IS-IS Topology tree diagram

7. YANG Model for IS-IS topology

This module imports types from [RFC8343] and [RFC8345]. Following the YANG model is presented.

```
   <CODE BEGINS> file "ietf-l3-isis-topology@2023-10-23.yang"
   module ietf-l3-isis-topology {
     yang-version 1.1;
     namespace
       "urn:ietf:params:xml:ns:yang:ietf-l3-isis-topology";
     prefix "isisnt";

     import ietf-network {
       prefix "nw";
       reference
         "RFC 8345: A YANG Data Model for Network Topologies";
     }

     import ietf-network-topology {
       prefix "nt";
       reference
         "RFC 8345: A YANG Data Model for Network Topologies";
     }

     import ietf-l3-unicast-topology {
       prefix "l3t";
       reference
         "RFC 8346: A YANG Data Model for Layer 3 Topologies";
     }

     import ietf-isis {
       prefix "ietf-isis";
       reference
         "RFC 9130: YANG Data Model for the IS-IS Protocols";
     }


     organization
       "IETF NMOP (Network Management Operations) Working Group";
     contact
       "WG Web:  <https://datatracker.ietf.org/wg/opsawg/>
       WG List:  <mailto:opsawg@ietf.org>

       Editor:   Oscar Gonzalez de Dios
                 <mailto:oscar.gonzalezdedios@telefonica.com>
       Editor:   Samier Barguil
                 <mailto:samier.barguil_giraldo@nokia.com>
       Editor:   Victor Lopez
                 <mailto:victor.lopez@nokia.com>
       Editor:   Benoit Claise
                 <mailto:benoit.claise@huwaei.com>";
     description
       "This module defines a model for Layer 3 ISIS
```

```
        topologies.

        Copyright (c) 2022 IETF Trust and the persons identified as
        authors of the code.  All rights reserved.

        Redistribution and use in source and binary forms, with or
        without modification, is permitted pursuant to, and subject to
        the license terms contained in, the Revised BSD License set
        forth in Section 4.c of the IETF Trust's Legal Provisions
        Relating to IETF Documents
        (https://trustee.ietf.org/license-info).

        This version of this YANG module is part of RFC XXXX
        (https://www.rfc-editor.org/info/rfcXXXX); see the RFC itself
        for full legal notices.";

     revision 2022-09-21 {
       description
         "Initial version";
       reference
         "RFC XXXX: A YANG Data Model for Intermediate System to
          Intermediate System (ISIS) Topology";
     }

     grouping isis-topology-type {
       description "Identifies the topology type to be ISIS.";
       container isis-topology {
         presence "indicates ISIS topology";
         description
           "The presence of the container node indicates ISIS
           topology";
       }
     }

     grouping isis-link-attributes {
        description "Identifies the IS-IS link attributes.";
        container isis-link-attributes {
         description
           "Main Container to identify the ISIS Link Attributes";
        leaf metric {
         type uint32 {
            range "0 .. 16777215";
          }
         description
           "This type defines wide style format of IS-IS metric.";
        }
        leaf level {
         type ietf-isis:level;
```

```
         description
           "Level of an IS-IS node - can be level-1,
           level-2 or level-all.";
        }
        }
      }

      grouping isis-node-attributes {
        description "isis node scope attributes";
        container isis-timer-attributes {
          description
            "Contains node timer attributes";
          uses ietf-isis:lsp-parameters;
        }
        container isis-node-attributes {
            description
              "Main Container to identify the ISIS Node Attributes";
          leaf system-id {
              type ietf-isis:system-id;
              description
                "System-id of the node.";
            }
          leaf level {
              type ietf-isis:level;
              description
                "Level of an IS-IS node - can be level-1,
                level-2 or level-all.";
            }
          leaf-list area-address {
              type ietf-isis:area-address;
              description
                "List of areas supported by the protocol instance.";
            }
          leaf lsp-lifetime {
              type uint16 {
                 range "1..65535";
               }
              units "seconds";
              description
                "Lifetime of the router's LSPs in seconds.";
            }
          leaf lsp-refresh-interval {
              type uint16 {
                 range "1..65535";
               }
              units "seconds";
              description
                "Refresh interval of the router's LSPs in seconds.";
```

```
          }
        }
      }

   grouping isis-termination-point-attributes {
       description "IS-IS termination point scope attributes";
       container isis-termination-point-attributes {
          description
         "Indicates the termination point from the
         which the IS-IS is configured. A termination
         point can be a physical port, an interface, etc.";

       leaf interface-type {
         type ietf-isis:interface-type;
         description
           "Type of adjacency (broadcast or point-to-point) to be established
           for the interface.
           This dictates the type of hello messages that are used.";
       }

       leaf level {
         type ietf-isis:level;
         description
           "Level of an IS-IS node - can be level-1,
           level-2 or level-all.";
       }

       leaf is-passive{
         type boolean;
         description
           "Indicates whether the interface is in passive mode (IS-IS
           not running but network is advertised).";
         }
       }
     }

     augment "/nw:networks/nw:network/nw:network-types" {
       description
         "Introduces new network type for L3 Unicast topology";
       uses isis-topology-type;
     }

     augment "/nw:networks/nw:network/nw:node/l3t:l3-node-attributes" {
       when "/nw:networks/nw:network/nw:network-types/isisnt:isis-topology" {
         description
           "Augmentation parameters apply only for networks with
           isis topology";
       }
```

```
        description
          "isis node-level attributes ";
        uses isis-node-attributes;
      }

      augment "/nw:networks/nw:network/nt:link/l3t:l3-link-attributes" {
        when "/nw:networks/nw:network/nw:network-types/isisnt:isis-topology" {
          description
            "Augmentation parameters apply only for networks with
            IS-IS topology";
        }
        description
          "Augments topology link configuration";
        uses isis-link-attributes;
      }



      augment "/nw:networks/nw:network/nw:node/nt:termination-point"+
      "/l3t:l3-termination-point-attributes" {
        when "/nw:networks/nw:network/nw:network-types/isisnt:isis-topology" {
          description
            "Augmentation parameters apply only for networks with
            IS-IS topology";
        }
        description
          "Augments topology termination point configuration";
        uses isis-termination-point-attributes;
      }
    }
    <CODE ENDS>
```

Figure 3: IS-IS Topology YANG module

8. Security Considerations

The YANG module specified in this document defines a schema for data that is 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 [RFC8446].

The Network Configuration Access Control Model (NACM) [RFC8341] 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.

There are a number of data nodes defined in this 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.

9. IANA Considerations

This document registers the following namespace URIs in the IETF XML registry [RFC3688]:

```
--------------------------------------------------------------------
URI: urn:ietf:params:xml:ns:yang:ietf-l3-isis-topology
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.
--------------------------------------------------------------------
```

This document registers the following YANG module in the YANG Module Names registry [RFC6020]:

```
--------------------------------------------------------------------
name:          ietf-l3-isis-topology
namespace:     urn:ietf:params:xml:ns:yang:ietf-l3-isis-topology
maintained by IANA: N
prefix:        ietf-l3-isis-topology
reference:     RFC XXXX
--------------------------------------------------------------------
```

10. References

10.1. Normative References

[I-D.draft-havel-opsawg-digital-map]
Havel, O., Claise, B., de Dios, O. G., Elhassany, A., Graf, T., and M. Boucadair, "Modeling the Digital Map based on RFC 8345: Sharing Experience and Perspectives", Work in Progress, Internet-Draft, draft-havel-opsawg-digital-map-01, 23 October 2023, <https://datatracker.ietf.org/doc/html/draft-havel-opsawg-digital-map-01>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/rfc/rfc2119>.

[RFC3688] Mealling, M., "The IETF XML Registry", BCP 81, RFC 3688, DOI 10.17487/RFC3688, January 2004, <https://www.rfc-editor.org/rfc/rfc3688>.

[RFC6020] Bjorklund, M., Ed., "YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)", RFC 6020, DOI 10.17487/RFC6020, October 2010, <https://www.rfc-editor.org/rfc/rfc6020>.

[RFC6242] Wasserman, M., "Using the NETCONF Protocol over Secure Shell (SSH)", RFC 6242, DOI 10.17487/RFC6242, June 2011, <https://www.rfc-editor.org/rfc/rfc6242>.

[RFC6991] Schoenwaelder, J., Ed., "Common YANG Data Types", RFC 6991, DOI 10.17487/RFC6991, July 2013, <https://www.rfc-editor.org/rfc/rfc6991>.

[RFC7950] Bjorklund, M., Ed., "The YANG 1.1 Data Modeling Language", RFC 7950, DOI 10.17487/RFC7950, August 2016, <https://www.rfc-editor.org/rfc/rfc7950>.

[RFC8040] Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", RFC 8040, DOI 10.17487/RFC8040, January 2017, <https://www.rfc-editor.org/rfc/rfc8040>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/rfc/rfc8174>.

[RFC8340] Bjorklund, M. and L. Berger, Ed., "YANG Tree Diagrams", BCP 215, RFC 8340, DOI 10.17487/RFC8340, March 2018, <https://www.rfc-editor.org/rfc/rfc8340>.

[RFC8341] Bierman, A. and M. Bjorklund, "Network Configuration Access Control Model", STD 91, RFC 8341, DOI 10.17487/RFC8341, March 2018, <https://www.rfc-editor.org/rfc/rfc8341>.

[RFC8342] Bjorklund, M., Schoenwaelder, J., Shafer, P., Watsen, K., and R. Wilton, "Network Management Datastore Architecture (NMDA)", RFC 8342, DOI 10.17487/RFC8342, March 2018, <https://www.rfc-editor.org/rfc/rfc8342>.

[RFC8343] Bjorklund, M., "A YANG Data Model for Interface Management", RFC 8343, DOI 10.17487/RFC8343, March 2018, <https://www.rfc-editor.org/rfc/rfc8343>.

[RFC8345] Clemm, A., Medved, J., Varga, R., Bahadur, N., Ananthakrishnan, H., and X. Liu, "A YANG Data Model for Network Topologies", RFC 8345, DOI 10.17487/RFC8345, March 2018, <https://www.rfc-editor.org/rfc/rfc8345>.

[RFC8346] Clemm, A., Medved, J., Varga, R., Liu, X., Ananthakrishnan, H., and N. Bahadur, "A YANG Data Model for Layer 3 Topologies", RFC 8346, DOI 10.17487/RFC8346, March 2018, <https://www.rfc-editor.org/rfc/rfc8346>.

[RFC8446] Rescorla, E., "The Transport Layer Security (TLS) Protocol Version 1.3", RFC 8446, DOI 10.17487/RFC8446, August 2018, <https://www.rfc-editor.org/rfc/rfc8446>.

[RFC8795] Liu, X., Bryskin, I., Beeram, V., Saad, T., Shah, H., and O. Gonzalez de Dios, "YANG Data Model for Traffic Engineering (TE) Topologies", RFC 8795, DOI 10.17487/RFC8795, August 2020, <https://www.rfc-editor.org/rfc/rfc8795>.

[RFC9130] Litkowski, S., Ed., Yeung, D., Lindem, A., Zhang, J., and L. Lhotka, "YANG Data Model for the IS-IS Protocol", RFC 9130, DOI 10.17487/RFC9130, October 2022, <https://www.rfc-editor.org/rfc/rfc9130>.

10.2. Informative References

[I-D.draft-ietf-teas-yang-l3-te-topo] Liu, X., Bryskin, I., Beeram, V. P., Saad, T., Shah, H. C., and O. G. de Dios, "YANG Data Model for Layer 3 TE Topologies", Work in Progress, Internet-Draft, draft-ietf-teas-yang-l3-te-topo-16, 2 March 2024, <https://datatracker.ietf.org/doc/html/draft-ietf-teas-yang-l3-te-topo-16>.

[RFC9552] Talaulikar, K., Ed., "Distribution of Link-State and Traffic Engineering Information Using BGP", RFC 9552, DOI 10.17487/RFC9552, December 2023, <https://www.rfc-editor.org/rfc/rfc9552>.

Appendix A. Implementation Status

Note to the RFC-Editor: Please remove this section before publishing.

A.1. Implementation Status in Telefonica Group

The Yang based topology model proposed in this draft is being used today in one of the Telefonica operations to export the Multi-vendor IP/MPLS topology based on multiple IS-IS domains to several Operation Support System tools for visualization, capacity planning and simulation. A commercial controller has implemented the exposure of the information. It is one of the building blocks to expose the network capabilities, together with other models which cover the inventory and service provisioning in a vendor-agnostic fashion.

A.2. Huawei Digital Map PoC Status

As mentioned in [I-D.draft-havel-opsawg-digital-map], a Digital Map PoC with a real lab has been built, based on multi- vendor devices, with [RFC8345] as the base YANG module for the topology building blocks. This PoC successfully modelled IS-IS routing (among other technologies and layers), but it needs to be further aligned with this latest developments in this draft.

A.3. Implementation Status in E-lighthouse Network Solutions

E-lighthouse Network Solutions (https://e-lighthouse.com/) implementation is consuming the IS-IS network topology information exported by a commercial controller, using the Yang model proposed in this draft. It is able to simulate the network behavior under different changes, covering the what-if, failure analysis, dimensioning and other use cases mentioned in this draft.

Acknowledgments

The authors would like to thank Pierre Francois for the review and suggestions the document.

This work is partially supported by the European Commission under grant agreement No. 101092766 (ALLEGRO Project) and Horizon 2020 Secured autonomic traffic management for a Tera of SDN flows (Teraflow) project (grant agreement number 101015857).

Contributors

Olga Havel
Huawei
Email: olga.havel@huawei.com

Pablo Pavon
Universidad Politecnica de Cartegena

Email: pablo.pavon@upct.es

Authors' Addresses

Oscar González de Dios
Telefonica
Email: oscar.gonzalezdedios@telefonica.com

Samier Barguil Giraldo
Nokia
Email: samier.barguil_giraldo@nokia.com

Victor Lopez
Nokia
Email: victor.lopez@nokia.com

Daniele Ceccarelli
Cisco
Email: dceccare@cisco.com

Benoit Claise
Huawei
Email: benoit.claise@huawei.com