Data Manifest for Streaming Telemetry
draft-claise-opsawg-collected-data-manifest-00

Abstract

Most network equipments feature telemetry as a mean to monitoring their status. Several protocols exist to this end; for example, the model-driven telemetry governed by YANG models. These protocols provide the data itself, without any contextual information about the collection method. This can render the data unusable if that context is lost, for instance when the data is stored without the relevant information. This draft proposes a YANG model to store that contextual information, that must be stored along with the collected data in order to keep the collected data exploitable.

Status of This Memo

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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.

Data Manifest: all the necessary metadata required to interpret the telemetry information.

Platform Manifest: part of the Data Manifest that completely identifies the platform producing the data.
2. Introduction

Network elements use Model-driven Telemetry (MDT) to continuously stream information, both counters and state information. This streamed information is used for network monitoring, directly in the data collection, in a closed-loop automation systems, or in a database (sometimes called a big data lake) for further analysis.

When streaming YANG objects with YANG-PUSH [RFC8641], there is a semantic definition in the corresponding YANG module definition. On top of that definition, it’s also important to understand any contextual information about the collection environment.

As an example, a database could contain a specific counter time series. When analyzing the data, it’s important to understand that this counter was requested from the network element at specific cadence, as this exact cadence might not be observed in the time series, potentially implying that the network element was under stress. The same time series might report some values as 0, or might even omit some values in the series. This might be explained by a too small observation period, compared to the minimum-observed-period [I-D.claise-netconf-metadata-for-collection]. Again, knowing the conditions under which the counter was collected and streamed is key. Indeed, taking into account the value of 0 might lead to the wrong conclusion that the counter dropped to zero. This document specifies the data manifest, which contains the information how and when the telemetry information were metered.

Precisely identifying the device used for producing the data (that is the platform manifest) is also key to complete the collection context. As an example, knowing the exact device software specification might reveal a particularity in the observed data, explained by a specific bug, or a specific bug fix. On top of that, in particular for MDT, it is crucial to know the set of YANG modules supported by the device, along with their deviation. In some cases, there might even be some backwards incompatible changes in native modules between one OS version to the next one. These information must be compiled in a platform manifest that must be included in the data manifest.

Some related YANG modules have been specified to discover the device capabilities:

- [I-D.ietf-netconf-notification-capabilities] which models the device capabilities regarding the production and export of telemetry data.
While these YANG modules are important to discover the capabilities before applying the telemetry configuration (such as on-change), some of this information is part of the context for the streaming data. Our goal is to represent the data manifest for a given device. This manifest contains two parts, the platform manifest and the data-collection manifest. The platform manifest is pretty stable and should change only when the device is updated or patched. On the other hand, the data collection is likely to change each time a new MDT subscription is requested and might even change if the device load increases and collection periods are updated. To separate these two parts, we enclose each of them in its own module. We first present the module for the platform manifest in Section 3 and then the module for the collection manifest in Section 4. The full data manifest is obtained by combining these two modules.

This data manifest instance file MUST be streamed all with the data and stored along with the collected data. In case the data are moved to different place (typically a database), the data manifest MUST follow the collected data. This can render the data unusable if that context is lost, for instance when the data is stored without the relevent information. The data manifest MUST be encoded with the YANG instance data file format
[I-D.ietf-netmod-yang-instance-file-format]. The YANG instance data file MUST be updated when the data manifest information changes (for example, when a router is upgraded), and the new timestamps MUST be used [I-D.ietf-netmod-yang-instance-file-format].

3. Platform Manifest

3.1. Overview of the model

Figure 1 contains the YANG tree diagram [RFC8340] of the ietf-collected-data-platform-manifest module.
module: ietf-collected-data-platform-manifest

++-rw platform
  +--rw platform?           string
  +--rw software-version?   string
  +--rw software-flavor?    string
  +--rw os-version?         string
  +--rw os-type?            string
  +--rw module-set* [name]
    +--rw name                  string
    +--rw module* [name]
      +--rw name         yang:yang-identifier
      +--rw revision?    revision-identifier
      +--rw namespace    inet:uri
      +--rw location*    inet:uri
      +--rw submodule* [name]
        +--rw name        yang:yang-identifier
        +--rw revision?   revision-identifier
        +--rw location*   inet:uri
        +--rw feature*    yang:yang-identifier
        +--rw deviation*  -> ../../module/name
    +--rw import-only-module* [name revision]
      +--rw name         yang:yang-identifier
      +--rw revision     union
      +--rw namespace    inet:uri
      +--rw location*    inet:uri
      +--rw submodule* [name]
        +--rw name        yang:yang-identifier
        +--rw revision?   revision-identifier
        +--rw location*   inet:uri

Figure 1: YANG tree diagram for ietf-collected-data-platform-manifest module

The platform manifest contains all the information to unambiguously identify a device. The platform is identified by a set of parameters (platform, software-version, software-flavor, os-version, os-type) that are aligned with the YANG Catalog [www.yangcatalog.org draft [I-D.clacla-netmod-model-catalog]] so that the YANG catalog could be used to retrieve the YANG modules a posteriori.

The platform manifest also includes the module-set, as defined in the YANG Library [RFC8525]. That module set is particularly useful to define to define the sensor paths, as they are based on module names.
3.2. YANG module ietf-collected-data-platform-manifest

<CODE BEGINS> file "ietf-collected-data-platform-manifest@2021-10-15.yang"

module ietf-collected-data-platform-manifest {
  yang-version 1.1;
  prefix platform-manifest;

  import ietf-yang-library {
    prefix yanglib;
    reference "RFC8525: YANG Library";
  }

  organization "IETF NETCONF (Network Configuration) Working Group";
  contact
    "WG Web: <https://datatracker.ietf.org/wg/netconf/>
    WG List: <mailto:netconf@ietf.org>
    Author: Benoit Claise <mailto:benoit.claise@huawei.com>
    Author: Jean Quilbeuf <mailto:jean.quilbeuf@huawei.com>";
  description
    "This module describes the platform information to be used as context of data collection from a given network element. The contents of this model must be streamed along with the data streamed from the network element so that the platform context of the data collection can be retrieved later.

    The data content of this model should not change except on upgrade or patching of the device.

    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 (RFC 2119) (RFC 8174) when, and only when, they appear in all capitals, as shown here.

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revision 2021-10-15 {
  description "Initial revision";
  reference "RFC xxxx: Title to be completed";
}

container platform {
  description "Contains information about the platform that allows to identify and understand the individual data collection information."
  leaf platform {
    type string;
    description "Platform on which this module is implemented.";
  }
  leaf software-version {
    type string;
    description "Name of the version of software. With respect to most network device appliances, this will be the operating system version. But for other YANG module implementation, this would be a version of appliance software. Ultimately, this should correspond to a version string that will be recognizable by the consumers of the platform.";
  }
  leaf software-flavor {
    type string;
    description "A variation of a specific version where YANG model support may be different. Depending on the vendor, this could be a license, additional software component, or a feature set.";
  }
  leaf os-version {
    type string;
    description "Version of the operating system using this module. This is primarily useful if the software implementing the module is an application that requires a specific operating system.";
  }
  leaf os-type {
    type string;
    description "Type of the operating system using this module. This is primarily useful if the software implementing the module is an application that requires a
4. Collection Manifest

4.1. Overview of the model

Figure 2 contains the YANG tree diagram [RFC8340] of the ietf-collected-data-manifest module.

module: ietf-collected-data-manifest
  +--rw data-collection
     +--rw mdt-collection-item* [sensor-path]
        +--rw sensor-path string
        +--rw requested-period? int64
        +--rw current-period? int64
        +--rw on-change? boolean
        +--rw suppress-redundancy? boolean

Figure 2: YANG tree diagram for ietf-collected-data-manifest module

The data-collection container contains the information related to individual items collection. This subtree currently contains only information about MDT collection. It should be extended and extendable to represent other kinds of data collection.

With MDT collection, the granularity of the collection is defined by the sensor path. Note that all devices do not support an arbitrary granularity up to the leaf, usually for performance reasons. Each sensor-path currently collected by the device should show up in the mdt-collection-item list.

For each sensor-path, the collection context must be specified including:

- on-change: when set to true, an update is sent as soon as and only when a value changes. This is also known as Event-Driven
Telemetry (EDT). When set to false, the values are sent regularly.

- suppress-redundancy (only when on-change is false): reduce bandwidth usage by sending a regular update only if the value is different from the previous update.

- requested-period (only when on-change is false): period between two updates requested by the client for this sensor-path

- current-period (only when on-change is false): current period between two updates

This information is crucial to understand the collected values. For instance, the on-change and suppress-redundancy options, if set, might remove a lot of messages from the database because values are sent only when there is a change.

4.2. YANG module ietf-collected-data-manifest

```
<CODE BEGINS> file "ietf-collected-data-manifest@2021-10-15.yang"

module ietf-collected-data-manifest {
  yang-version 1.1;
  prefix data-manifest;

  organization
    "IETF NETCONF (Network Configuration) Working Group";
  contact
    "WG Web:  <https://datatracker.ietf.org/wg/netconf/>
    WG List: <mailto:netconf@ietf.org>
    Author:  Benoit Claise  <mailto:benoit.claise@huawei.com>
    Author:  Jean Quilbeuf  <mailto:jean.quilbeuf@huawei.com>";
  description
    "This module describes the context of data collection from a
given network element. The contents of this model must be
streamed along with the data streamed from the network
element so that the context of the data collection can
be retrieved later.

This module must be completed with
ietf-collected-data-platform-manifest
to capture the whole context of a data collection session.

The key words ‘MUST’, ‘MUST NOT’, ‘REQUIRED’, ‘SHALL’,
‘NOT RECOMMENDED’, ‘MAY’, and ‘OPTIONAL’ in this document
```

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RFC itself for full legal notices.

revision 2021-10-15 {
  description
    "Initial revision";
  reference
    "RFC xxxx: Title to be completed";
}

container data-collection {
  description
    "Defines the information for each collected objet";
  list mdt-collection-item {
    description
      "Status of the collection for the given sensor-path";
    key "sensor-path";
    leaf sensor-path {
      description
        "The sensor path that was configured to collect information about
        this object. Sensor path syntax is
        module_name:node_name ( / (module_name:)? node_name)*
        where module_name is the name of a module and node_name is the
        name of a node (list, container or leaf). Module name is only
        necessary if the preceding node in the path is not defined in
        the same module.
        Module name must be defined in the platform-manifest module and
        every node name must be defined in the preceding manifest module in
        the path.";
      type string;
    }
    leaf requested-period {
      description
        "Requested period, in milisecond, between two succesive updates.";
      type int64;
    }
}
// when on-change is false;
}
leaf current-period {
  description
  "Current period, in milisecond, between two successive update.s";
  type int64;
  // when on-change is false;
}
leaf on-change {
  description
  "Whether the sensor path is collected only when there is a change,
  i.e. Event-Driven Telemetry is enabled.";
  type boolean;
}
leaf suppress-redundancy {
  description
  "Whether the information is sent at every period or only when there
  is a change between two successive pollings..");
  type boolean;
}
// we could augment here with other kind of collection items
}

<CODE ENDS>

5. Mapping data to data manifest

The data should be mapped to the data manifest. Since the data manifest will not change as frequently as the data itself, it makes sense to map several data to the same data manifest. Somehow, the collected data must include a metadata pointing to the corresponding data manifest.

The platform manifest is likely to remain the same until the device is updated. So the platform manifest only need to be collected once per streaming session and updated after a device reboot.

For MDT, we can rely on the sensor-path to map the collected data to the data manifest. In that sense, collecting one instance of the data-manifest per device is sufficient to get the data manifest of all data connected from that device.
6. Security Considerations

7. IANA Considerations

This document includes no request to IANA.

8. Contributors

9. Open Issues

- Do we want to the hardware specifications, next to the OS information?
- Do we want to handle the absence of values, i.e. add information about missed collection or errors in the collection context? It could also explain why some values are missing. On the other hand, this might also be out of scope.
- How do we handle other kinds of collection than MDT like netflow, SNMP, CLI? How do we map the collected data to the data-manifest?
- Align the terms with the YANG Push specifications. Ex: sensor-path to subscription (TBC)
- Better explain the on-change example.

10. References

10.1. Normative References

[I-D.ietf-netmod-yang-instance-file-format]


10.2. Informative References

[I-D.clacla-netmod-model-catalog]

[I-D.claise-netconf-metadata-for-collection]

[I-D.ietf-netconf-notification-capabilities]

Appendix A. Changes between revisions

Initial version

Acknowledgements

Authors’ Addresses

Benoit Claise
Huawei

Email: benoit.claise@huawei.com

Jean Quilbeuf
Huawei

Email: jean.quilbeuf@huawei.com
Diego R. Lopez
Telefonica I+D
Don Ramon de la Cruz, 82
Madrid   28006
Spain

Email: diego.r.lopez@telefonica.com

Thomas Graf
Swisscom
Binzring 17
Zurich   8045
Switzerland

Email: thomas.graf@swisscom.com
Abstract

This document defines a YANG data model for representing an abstract view of the provider network topology containing the points from which its services can be attached (e.g., basic connectivity, VPN, network slices). The data model augments the 'ietf-network' data model by adding the concept of service attachment points (SAPs). The service attachment points are the points to which network services (such as L3VPN or L2VPN) can be attached. The customer endpoint of an attachment circuits are not covered in the SAP network topology.

Status of This Memo

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1. Introduction

The service attachment point (SAP) is an important architectural concept in many implementations and deployments of services such as VPNs, SDWAN, or managed VoIP services. It has already been used to decide where to attach and, thus, deliver the service in the L3SM [RFC8299] and the L2SM [RFC8466].

This document defines a YANG network model for representing, managing, and controlling the service attachment points (SAPs). The data model augments the 'ietf-network' module [RFC8345] by adding the concept of service attachment points. The service attachment points are abstraction of the points where network services such as L3VPNs or L2VPNs can be attached.

This document does not make any assumption about the service provided by the network to the users. VPN services are used for illustration purposes. This concept can also be used to decide network slice SAPs [I-D.ietf-teas-ietf-network-slices].

In the context of Software-Defined Networking (SDN) [RFC7149][RFC7426], the defined YANG data model in this document can be used to exchange information between control elements, so as to...
support VPN service provision and resource management discussed in
[I-D.ietf-opsawg-l3sm-l3nm][I-D.ietf-opsawg-l2nm]. Through this data
model, the service orchestration layer can learn the available
endpoints (i.e., SAPs) of interconnection resource of the underlying
network.

The service orchestration layer can determine which endpoint of
interconnection to add to L2VPN or L3VPN service. With the help of
other data models (e.g., L3SM [RFC8299] or L2SM [RFC8466]),
hierarchical control elements could determine the feasibility of an
end-to-end IP connectivity or L2VPN connectivity and therefore derive
the sequence of domains and the points of interconnection to use.

This document explains the scope and purpose of a SAP network model
and its relation with the service models and describes how it can be
used by a network operator. The document also shows how the topology
and service models fit together.

The YANG data model in this document conforms to the Network
Management Datastore Architecture (NMDA) [RFC8342].

2. 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.

This document assumes that the reader is familiar with the contents
of [RFC6241], [RFC7950], and [RFC8309]. The document uses terms from
those documents.

Tree diagrams used in this document follow the notation defined in
[RFC8340].

This document uses the term "network model" defined in Section 2.1 of
[RFC8969].

This document uses the following terms:

Service Provider (SP): The organization responsible for operating
the network that offers a service (e.g., a VPN) to customers.

Customer Edge (CE): An equipment that is dedicated to a particular
customer and is directly connected to one or more Provider Edges
(PEs) via attachment circuits (ACs). A CE is usually located at
the customer premises. A CE may be dedicated to a single service
(e.g., L3VPN), although it may support multiple VPNs if each one has separate attachment circuits. A CE can be a router, bridge, switch, etc.

Provider Edge (PE): An equipment owned and managed by the SP that can support multiple services (e.g., VPNs) for different customers. A PE is directly connected to one or more CEs via attachment circuits. A PE is usually located at an SP point of presence (PoP).

Attachment point (AP): Describes a service’s end point characteristics and its reference to a Termination Point (TP) of the PE; used as service access point for service.

3. SAP Network Model Usage

Management operations of a service provider network can be automated using a variety of means such as interfaces based on YANG modules [RFC8969]. From that standpoint, and considering the architecture depicted in Figure 1, the goal of this document is to provide a mechanism to show via a YANG-based interface an abstracted network view from the network controller to the service orchestration layer with a focus on where a service can be delivered to customers.

Figure 1: SAP Network Model Usage

Let us consider the example of a typical service provider network (Figure 2), with PE and P nodes.
The Service Orchestration layer does not need to know about the internals of the underlying network (e.g., P nodes). Figure 3 shows the abstract network view as seen by the Service Orchestrator. However, this view is not enough to provide to the Service Orchestration layer the information to create services in the network. The service topology need is to be able to expose the set of nodes and the attachment points associated with the nodes from which network services can be grafted (delivered).

The Service Orchestration layer would see a set of PEs and a set of client-facing interfaces (physical or logical) to which CEs can be connected (or are actually connected). The Service Orchestration layer can use them to setup the requested services or to commit the delivery of a service. Figure 4 depicts the SAP network topology that is maintained by the network controller and exposed to the Service Orchestration.
A single SAP network topology can be used for one of multiple service types (e.g., L3VPN, EVPN). The network controller can then expose the service type(s) and associated interfaces via the SAPs.

As shown in Figure 5, the Service Orchestration layer will have also access to a set of Customer Service Model, e.g., an L3SM or L2SM data model in the customer-facing interface and a set of network models, e.g., L3NM and Network topology data models in the resource-facing interface. In this use case, it is assumed that the network controller is unaware of what happens beyond the PEs towards the CEs; it is only responsible for the management and control of the network between PEs.
4. SAP Module Tree Structure

The SAP network model builds on the network data model defined in the 'ietf-network' module [RFC8345], augmenting the nodes with service attachment points, which anchor the links and are contained in nodes. The 'service-attachment-point' attribute defined in the SAP network model is not a tunnel termination point (TTP) nor a link, but an abstraction of the termination point defined in [RFC8345].

The structure of the 'ietf-sap-ntw' module is shown in Figure 6.
A SAP network topology can be used for one single service type or multiple types ("sap-type"). When a SAP topology is used for many service types, the underlying nodes must support at least one of these service types. Examples of supported service types are listed below:

* L3VPN,
* Virtual Private LAN Service (VPLS) using BGP [RFC4761],
* VPLS using Label Distribution Protocol (LDP) [RFC4762],
* Virtual Private Wire Service (VPWS) [RFC8214],
* BGP MPLS-Based Ethernet VPN [RFC7432],
* Ethernet VPN (EVPN) [RFC8365],
* Provider Backbone Bridging Combined with Ethernet VPN (PBB-EVPN) [RFC7623],
* Virtual Networks [RFC8453],
* Enhanced VPN (VPN+) [I-D.ietf-teas-enhanced-vpn], and
* Network slice [I-D.ietf-teas-ietf-network-slices].
A service attachment point is identified by an interface name ("attachment-id"), an interface type ("type"), a status ("admin-status", and "oper-status"), an encapsulation type ("encapsulation-type"), one or a list of service types ("sap-type") such as L3VPN or network slice, a description of the service(s) ("service-description").

5. Relation with other Models

The SAP network model can be seen as an inventory data associated with service attachment points. The model maintains an inventory of nodes contained in a network based on [RFC8345].

Figure 7: Relation of SAP Network Model to Other Models

Figure 7 depicts the relationship of the SAP network model to other models. The SAP network model augments from the Network model [RFC8345] and imports Network Topology model, while other technology-specific topology models (e.g., TE Topologies model [RFC8795] or L3 Topology model [RFC8346]) augment from the Network Topology.

6. SAP YANG Module

This module imports types from [RFC8343], [RFC8345], and [I-D.ietf-opsawg-vpn-common].
<CODE BEGINS> file "ietf-sap-ntw@2021-10-16.yang"
module ietf-sap-ntw { 
yang-version 1.1; 
prefix sap;

import ietf-interfaces { 
  prefix if;
  reference
    "RFC 8343: A YANG Data Model for Interface Management";
}
import ietf-network-topology { 
  prefix nt;
  reference
    "RFC 8345: A YANG Data Model for Network Topologies, Section 6.2";
}
import ietf-network { 
  prefix nw;
  reference
    "RFC 8345: A YANG Data Model for Network Topologies, Section 6.1";
}
import ietf-vpn-common { 
  prefix vpn-common;
  reference
    "RFC UUUU: A Layer 2/3 VPN Common YANG Model";
}

organization 
  "IETF OPSA (Operations and Management Area) Working Group ";
contact 
  "Editor:   Oscar Gonzalez de Dios
  <mailto:oscar.gonzalezdedios@telefonica.com>
Editor:   Samier Barguil
  <mailto:samier.barguilgiraldo.ext@telefonica.com>
Editor:   Qin Wu
  <mailto:bill.wu@huawei.com>
Editor:   Mohamed Boucadair
  <mailto:mohamed.boucadair@orange.com>"

description
  "This YANG module defines a model for representing, managing, and controlling the Service Attachment Points (SAPs) in the network topology."

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revision 2021-10-16 {
    description
        "Initial version";
    reference
        "RFC XXXX: A Network YANG Model for Service Attachment Point (SAP)";
}

identity service-type {
    description
        "Base identity for the service type.";
}

identity l3vpn {
    base service-type;
    description
        "L3VPN service.";
    reference
        "RFC 4364: BGP/MPLS IP Virtual Private Networks (VPNs)";
}

identity enhanced-vpn {
    base service-type;
    description
        "Enhanced VPN (VPN+). VPN+ is an approach that is based on existing VPN and Traffic Engineering (TE) technologies but adds characteristics that specific services require over and above traditional VPNs.";
    reference
        "I-D.ietf-teas-enhanced-vpn: A Framework for Enhanced Virtual Private Network (VPN+) Services";
}

identity network-slice {
    base service-type;
    description
"IETF network slice. An IETF network slice is a logical network topology connecting a number of endpoints using a set of shared or dedicated network resources that are used to satisfy specific service objectives."

- reference
  - "I-D.ietf-teas-ietf-network-slices:
    Framework for IETF Network Slices"


```ini
identity vpls {
    base service-type;
    description
    "VPLS service."
    reference
    "RFC 4761: Virtual Private LAN Service (VPLS) Using BGP for Auto-Discovery and Signaling
    RFC 4762: Virtual Private LAN Service (VPLS) Using Label Distribution Protocol (LDP) Signaling"
}
```

```ini
identity vpws {
    base service-type;
    description
    "Virtual Private Wire Service (VPWS) service."
    reference
    "RFC 4664: Framework for Layer 2 Virtual Private Networks (L2VPNs), Section 3.1.1"
}
```

```ini
identity vpws-evpn {
    base service-type;
    description
    "EVPN used to support VPWS service."
    reference
    "RFC 8214: Virtual Private Wire Service Support in Ethernet VPN"
}
```

```ini
identity pbb-evpn {
    base service-type;
    description
    "Provider Backbone Bridging (PBB) EVPNs service."
    reference
    "RFC 7623: Provider Backbone Bridging Combined with Ethernet VPN (PBB-EVPN)"
}
```

```ini
identity mpls-evpn {
    base service-type;
    description
    "MPLS EVPNs service."
    reference
    "RFC 8848: MPLS EVPNs using Segment Routing"
}
```

- reference
  - "I-D.ietf-teas-ietf-network-slices:
    Framework for IETF Network Slices"

```ini
identity mpls-evpn {
    base service-type;
    description
    "MPLS EVPNs service."
    reference
    "RFC 8848: MPLS EVPNs using Segment Routing"
}
```

- reference
  - "I-D.ietf-teas-ietf-network-slices:
    Framework for IETF Network Slices"
identity vxlan-evpn {
  base service-type;
  description "VXLAN-based EVPN service.";
  reference "RFC 8365: A Network Virtualization Overlay Solution Using Ethernet VPN (EVPN)";
}

identity virtual-network {
  base service-type;
  description "Virtual network.";
  reference "RFC 8453: Framework for Abstraction and Control of TE Networks (ACTN)";
}

/*
Other network service types may be added.
*/

grouping sap-information {
  description "Service Attachment Point (SAP) information.";
  list service-attachment-point {
    key "attachment-id";
    description "The service attachment points are abstraction of the points where network services such as L3VPNs, L2VPNs, or network slices can be attached.";
    leaf attachment-id {
      type nt:tp-id;
      description "Indicates the name of the interface.";
    }
    leaf interface-type {
      type identityref {
        base if:interface-type;
      }
      config false;
    }
description
"The type of the interface.";
)
leaf admin-status {
  type boolean;
  description
  "Indicates the administrative status of the SAP.";
}
leaf oper-status {
  type boolean;
  description
  "Indicates the operational status.";
}
leaf encapsulation-type {
  type identityref {
    base vpn-common:encapsulation-type;
  }
  description
  "Encapsulation type.";
}
leaf-list sap-type {
  type identityref {
    base service-type;
  }
  description
  "SAP type.";
}
leaf service-description {
  type string;
  description
  "A textual description of the service(s).";
}
}
}

augment "/nw:networks/nw:network/nw:network-types" {
  description
  "Introduces a new network type for SAP network.";
  container sap-network {
    presence "Indicates SAP Network Type.";
    description
    "The presence of the container node indicates the SAP network type.";
    leaf-list sap-type {
      type identityref {
        base service-type;
      }
    description
    }
"Indicates a service type."

augment "/nw:networks/nw:network/nw:node" {
  description
    "Parameters for the service attachment point level.";
  uses sap-information;
}

7. IANA Considerations

This document registers the following namespace URI in the "ns" subregistry within the "IETF XML Registry" [RFC3688]:

  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] within the "YANG Parameters" registry:

  name: ietf-sap-ntw
  maintained by IANA: N
  prefix: sap
  reference: RFC XXXX

8. Security Considerations

The YANG module specified in this document defines 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. These are the subtrees and data nodes and their sensitivity/vulnerability:

* /nw:networks/nw:network/nw:node/sap:service-attachment-point/sap:attachment-id

This subtree specifies the configurations of the nodes in a SAP network model. Unexpected changes to this subtree could lead to service disruption and/or network misbehavior.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via get, get-config, or notification) to these data nodes. These are the subtrees and data nodes and their sensitivity/vulnerability:

* /nw:networks/nw:network/nw:node/sap:service-attachment-point

Unauthorized access to this subtree can disclose the operational state information of the nodes in a SAP network model.

9. Acknowledgements

Thanks to Adrian Farrell and Daniel King for the suggestions on the names used in a previous version.

10. References

10.1. Normative References


10.2. Informative References

[I-D.ietf-opsawg-l2nm]

[I-D.ietf-opsawg-l3sm-l3nm]

[I-D.ietf-teas-enhanced-vpn]

[I-D.ietf-teas-ietf-network-slices]


Authors’ Addresses

Oscar Gonzalez de Dios
Telefonica
Madrid
Spain

Email: oscar.gonzalezdedios@telefonica.com

Samier Barguil
Telefonica
Madrid
Spain

Email: samier.barguilgiraldo.ext@telefonica.com
Problem Statement and Requirement for Inband Flow Learning
draft-hwyh-ippm-ps-inband-flow-learning-01

Abstract

Alternate-Marking (coloring) provides a method to perform packet loss, delay, and jitter measurements on live traffic. At the same time, on-path telemetry techniques are used to enable the collection and correlation of performance information to further support autonomous network operations. However, network operators still face the challenge of inband flow identification in large scale deployment. This document addresses the problems by introducing the real network scenarios, and proposes the requirements of supporting inband flow learning of flow information telemetry.

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 BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

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This Internet-Draft will expire on 28 April 2022.
1. Introduction

Alternate-Marking (coloring) [RFC8321] provides a method to perform packet loss, delay, and jitter measurements on live traffic. [I-D.ietf-mpls-inband-pm-encapsulation] and [I-D.ietf-6man-ipv6-alt-mark] introduce the MPLS and IPv6 performance measurement applications of alternate marking method respectively, and specifies the encapsulations for MPLS and IPv6. On-path telemetry techniques are used to enable the collection and correlation of performance information from the network. By coloring
the real service flow and telemetry flow statistics, per-flow SLA compliance monitoring becomes available and scalable for network operators. When deployed in network, per-flow monitoring can be applied based on CLI configuration or via Netconf YANG.

However, even though Netconf YANG can provide feasibility to network administration, the characteristic of a flow (e.g. IP 5-tuple) can vary dynamically and mislead the service flow identification. Inband flow learning becomes a challenge in large scale deployment to network operators. This document addresses the problems by introducing the real network scenarios, and proposes the requirements of supporting inband flow learning of flow information telemetry.

2. Terminology

OAM: Operations, Administration, and Maintenance

SLA: Service Level Agreement

NFV: Network Function Virtualization

UNI: User-Network-Interface

CN: Core Network

3. Problem Statement

In an alternate marking application, it is usually to utilize the characteristic fields of packet to identify a service flow. For example, IP 5-tuple is usually to be used as the identifier of a service flow at source node. A concept of flow identifier, such as Flow-ID Label Indicator [I-D.ietf-mpls-inband-pm-encapsulation] or FlowMonID [I-D.ietf-6man-ipv6-alt-mark] is used to identify service flow at transit or egress nodes. The change of packet data fields would mislead the flow identification for flow monitoring and statistics telemetry in large scale.

3.1. Frequent and Dynamic Change of Flows

In 4G/5G mobile backhaul networks, IP address of one service can be changed based on location, time or even with business growth. The following scenarios describes the challenges which 4G/5G mobile service encounters.
3.1.1. Tidal Effect

A Tidal Effect phenomenon has been recognized as traffics between base station and Core Network (CN) show repetitive patterns with spatio-temporal variations. A typical example of Tidal phenomenon is the traffic difference happened in day and night time of a commercial and business area. In day time, eNodeB allocates more core network resources when a large number of user equipment accesses eNodeB, and less resources at night accordingly. The change of the number of UEs and the core network resources may affect the change on source and destination IP address of service flows.

Moreover, NFV used in core network makes the traffic change even worse as the IP address at CN cannot be manually configured or even predicted. In this case, it is impossible for operators to statically deploy flow monitoring and statistics telemetry.

3.1.2. UPF Expansion

In 5G deployment, the increase of number of subscribers triggers the expansion of UPF resources on data plane of 5G core network. After new UPF resource is added, eNodeB sets up a connection to the new UPF. Correspondingly, a new IP flow is created in mobile bearer network. In this scenario, if flow monitoring and statistics telemetry is deployed in a static mode, operators would need to manually add related configurations to mobile bearer network after the core network capacity is expanded, which is very difficult to deploy in practice.

3.2. Enterprise Service Demand

The enterprise services usually connect different private networks between Headquarter and Branches, Branches and Branches. Network operator has very limited or even no information about end users. Besides, information from one site could be changed from time to time. Unpredictable information on enterprise customer side makes it impossible for network operators to set up real time flow monitoring, and to avoid the omission of flow monitoring.

3.3. Large Scale Network Monitor Deployment and Maintenance

In a large-scale mobile bearer network, a large number of base stations and corresponding access points may lead to a large number of IP addresses in core network. From network maintenance perspective, when flow monitoring and statistics telemetry is deployed in a static mode, network operator had to manually set up each monitoring instance between base station and core network, then separately delegate configurations to a large number of network
entities. It is difficult for network operators to find an effective way of monitoring creation and maintenance.

Note that traffic monitoring is comprised of uplink and downlink directions, which makes twice of workload on configurations.

3.4. Service Flow Path Change

When a hop-by-hop flow monitoring is required by critical traffic for deep SLA investigation, the actual forwarding path of service flow and the every forwarding nodes along the path are obtained. Network operator delegates different configurations to each node including ingress, transit, and egress nodes on the path.

Once the traffic forwarding path is changed because of service flow switching or route convergence, the monitoring instance on each node needs to be re-deployed on the new path. In this situation, a flexible and efficient deployment approach is required by network operators.

4. Requirement

To face the flow deployment challenges mentioned in preceding section, an approach of inband flow learning is required. It should simplify the deployment of flow monitoring and achieve an automatic mode of telemetry in large scale networks.

4.1. Ingress Flow Learning

On the UNI side of network node, ingress flow learning can help to capture the characteristic data fields of packet and create the monitoring instance when the flow is created from base station. Flexible policy based on access control list (ACL) can facilitate the identification of flow characteristic. For example, IP 2-tuple (DIP+SIP), DSCP value, etc.

4.2. Egress Flow Learning

Similar to the requirement on ingress node, traffic egress node should support the same capability of inband flow learning to create traffic monitoring instance for completing a monitor. When the egress node or egress port of a service flow is changed, the egress node or egress port of service flow can be triggered to re-learn and re-monitor the service flow.
4.3. Hop-by-Hop Flow Learning

When hop-by-hop flow monitoring and telemetry is required, the flow learning and monitor deployment should be created on all the ingress, transit, and egress nodes that service flows pass through. When the path of a service flow changes due to the service switching or network convergence, the service flow re-triggers the flow learning on the new path and starts the new monitoring of service flow.

4.4. Auto Flow Aging

In all the inband flow learning scenarios described above, when the path of a service flow changes, the flow learning on new path is triggered and new monitoring instances are created on devices. Regarding the monitoring instances that have been created before the path change, if there is no traffic detected within a certain period of time, automatic aging and resource recycle should be supported.

4.5. Flow Learning Policy

It is valuable to specify the flow learning policy on equipment when thousands or millions of flows are transmitted. Flow learning policy specifies the metrics and explicit rules executed on equipment, for example the flow is filtered based on a particular range of protocol number. Centralized controller specifies the flow learning policy via management and control plane to equipment, then data plane executes the policies to generate monitoring instance.

5. IANA Considerations

This document has no request to IANA

6. Security Considerations

TBD

7. References

7.1. Normative References

7.2. Informative References

[I-D.ietf-6man-ipv6-alt-mark]

[I-D.ietf-mpls-inband-pm-encapsulation]


Authors’ Addresses

Liuyan Han
China Mobile
Beijing
China

Email: hanliuyan@chinamobile.com

Minxue Wang
China Mobile
Beijing
China

Email: wangminxue@chinamobile.com
Operational Considerations for use of DNS in IoT devices
draft-ietf-opsawg-mud-iot-dns-considerations-02

Abstract

This document details concerns about how Internet of Things devices use IP addresses and DNS names. The issue becomes acute as network operators begin deploying RFC8520 Manufacturer Usage Description (MUD) definitions to control device access.

This document explains the problem through a series of examples of what can go wrong, and then provides some advice on how a device manufacturer can best make deal with these issues. The recommendations have an impact upon device and network protocol design.

{RFC-EDITOR, please remove. Markdown and issue tracker for this document is at https://github.com/mcr/iot-mud-dns-considerations.git}

Status of This Memo

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1. Introduction

[RFC8520] provides a standardized way to describe how a specific purpose device makes use of Internet resources. Access Control Lists (ACLs) can be defined in an RFC8520 Manufacturer Usage Description (MUD) file that permit a device to access Internet resources by DNS name.
Use of a DNS name rather than IP address in the ACL has many advantages: not only does the layer of indirection permit the mapping of name to IP address to be changed over time, it also generalizes automatically to IPv4 and IPv6 addresses, as well as permitting loading balancing of traffic by many different common ways, including geography.

At the MUD policy enforcement point – the firewall – there is a problem. The firewall has only access to the layer-3 headers of the packet. This includes the source and destination IP address, and if not encrypted by IPsec, the destination UDP or TCP port number present in the transport header. The DNS name is not present!

It has been suggested that one answer to this problem is to provide a forced intermediate for the TLS connections. This could in theory be done for TLS 1.2 connections. The MUD policy enforcement point could observe the Server Name Identifier (SNI) [RFC6066]. Some Enterprises do this already. But, as this involves active termination of the TCP connection (a forced circuit proxy) in order to see enough of the traffic, it requires significant effort. But, TLS 1.3 provides options to encrypt the SNI as the ESNI, which renders the practice useless in the end.

So in order to implement these name based ACLs, there must be a mapping between the names in the ACLs and layer-3 IP addresses. The first section of this document details a few strategies that are used.

The second section of this document details how common manufacturer anti-patterns get in the way this mapping.

The third section of this document details how current trends in DNS presolution such as public DNS servers, DNS over TLS (DoT), and DNS over HTTPS (DoH) cause problems for the strategies employed. Poor interactions with content-distribution networks is a frequent pathology that can result.

The fourth section of this document makes a series of recommendations ("best current practices") for manufacturers on how to use DNS, and IP addresses with specific purpose IoT devices.

The Privacy Considerations section concerns itself with issues that DNS-over-TLS and DNS-over-HTTPS are frequently used to deal with. How these concerns apply to IoT devices located within a residence or enterprise is a key concern.
The Security Considerations section covers some of the negative outcomes should MUD/firewall managers and IoT manufacturers choose not to cooperate.

2. 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.

This document is a Best Current Practices (BCP) document. It uses the above language where it needs to make a normative requirement on implementations.

3. Strategies to map names

The most naive method is to try to map IP addresses to names using the in-addr.arpa (IPv4), and ipv6.arpa (IPv6) mappings. This fails for a number of reasons:

1. it can not be done fast enough,
2. it reveals usage patterns of the devices,
3. the mapping are often incomplete,
4. even if the mapping is present, due to virtual hosting, it may not map back to the name used in the ACL.

This is not a successful strategy, and do not use it.

XXX -- explain in detail how this can fail.

XXX -- explain N:1 vs 1:1 for virtual hosting.

The simplest successful strategy for translating names is for a MUD controller to take is to do a DNS lookup on the name (a forward lookup), and then use the resulting IP addresses to populate the physical ACLs.

There are still a number of failures possible.

The most important one is in the mapping of the names to IP addresses may be non-deterministic. [RFC1794] describes the very common mechanism that returns DNS A (or reasonably AAAA) records in a permuted order. This is known as Round Robin DNS, and it has been
used for many decades. The device is intended to use the first IP
address that is returned, and each query returns addresses in a
different ordering, splitting the load among many servers.

This situation does not result in failures as long as all possible A/
AAAA records are returned. The MUD controller and the device get a
matching set, and the ACLs that are setup cover all possibilities.

There are a number of circumstances in which the list is not
exhaustive. The simplest is when the round robin does not return all
addresses. This is routinely done by geographical DNS load balancing
system. It can also happen if there are more addresses than will
conveniently fit into a DNS reply. The reply will be marked as
truncated. (If DNSSEC resolution will be done, then the entire RR
must be retrieved over TCP (or using a larger EDNS(0) size) before
being validated)

However, in a geographical DNS load balancing system, different
answers are given based upon the locality of the system asking.
There may also be further layers of round-robin indirection.

Aside from the list of records being incomplete, the list may have
changed between the time that the MUD controller did the lookup and
the time that the IoT device does the lookup, and this change can
result in a failure for the ACL to match.

In order to compensate for this, the MUD controller SHOULD regularly
do DNS lookups. These lookups need to be rate limited in order to
avoid load. It may be necessary to avoid recursive DNS servers in
order to avoid receiving cached data. Properly designed recursive
servers should cache data for many minutes to days, while the
underlying DNS data can change at a higher frequency, providing
different answers to different queries!

A MUD controller that is aware of which recursive DNS server that the
IoT device will use can instead query that server on a periodic
basis. Doing so provides three advantages:

1. any geographic load balancing will base the decision on the
geo location of the recursive DNS server, and the recursive name
server will provide the same answer to the MUD controller as to
the IoT device.

2. the resulting name to IP address mapping in the recursive name
server will be cached, and will remain the same for the entire
advertised Time-To-Live reported in the DNS query return. This
also allows the MUD controller to avoid doing unnecessary
queries.
3. If any addresses have been omitted in a round-robin DNS process, the cache will have the set of addresses that were returned.

The solution of using the same caching recursive resolver as the target device is very simple when the MUD controller is located in a residential CPE device. The device is usually also the policy enforcement point for the ACLs, and a caching resolver is typically located on the same device. In addition the convenience, there is a shared fate advantage: as all three components are running on the same device, if the device is rebooted, clearing the cache, then all three components will get restarted when the device is restarted.

Where the solution is more complex is when the MUD controller is located elsewhere in an Enterprise, or remotely in a cloud such as when a Software Defines Network (SDN) is used to manage the ACLs. The DNS servers for a particular device may not be known to the MUD controller, nor the MUD controller be even permitted to make recursive queries that server if it is known. In this case, additional installation specific mechanisms are probably needed to get the right view of DNS.

4. DNS and IP Anti-Patterns for IoT device Manufacturers

In many design fields, there are good patterns that should be emulated, and often there are patterns that should not be emulated. The latter are called anti-patterns, as per [antipatterns].

This section describes a number of things with IoT manufacturers have been observed to do in the field, each of which presents difficulties for MUD enforcement points.

4.1. Use of IP address literals in-protocol

A common pattern for a number of devices is to look for firmware updates in a two step process. An initial query is made (often over HTTPS, sometimes with a POST, but the method is immaterial) to an authoritative server. (What is this) The current firmware model of the device is sometimes provided and then the authoritative server provides a determination if a new version is required, and if so, what version. In simpler cases, an HTTPS end point is queried which provides the name and URL of the most recent firmware.

The authoritative upgrade server then responds with a URL of a firmware blob that the device should download and install. Best practice is that firmware is either signed internally ([I-D.ietf-suit-architecture]) so that it can be verified, or a hash of the blob is provided.
An authoritative server might be tempted to provide an IP address literal inside the protocol: there are two arguments (anti-patterns) for doing this.

One is that it eliminates problems to firmware updates that might be caused by lack of DNS, or incompatibilities with DNS. For instance the bug that causes interoperability issues with some recursive servers would become unpatchable for devices that were forced to use that recursive resolver type.

A second reason to avoid a DNS in the URL is when an inhouse content-distribution system is involved that involves on-demand instances being added (or removed) from a cloud computing architecture.

But, there are many problems with use of IP address literals for the location of the firmware.

The first is that the update service server must decide whether to provide an IPv4 or an IPv6 literal. A DNS name can contain both kinds of addresses, and can also contain many different IP addresses of each kind.

The second problem is that it forces the MUD file definition to contain the exact same IP address literals. It must also contain an ACL for each address literal. DNS provides a useful indirection method that naturally aggregates the addresses.

A third problem involves the use of HTTPS. IP address literals do not provide enough context for TLS ServerNameIndicator to be useful [RFC6066]. This limits the firmware repository to be a single tenant on that IP address, and for IPv4 (at least), this is no longer a sustainable use of IP addresses.

And with any non-deterministic name or address that is returned, the MUD controller is not challenged to validate the transaction, as it can not see into the communication.

Third-party content-distribution networks (CDN) tend to use DNS names in order to isolate the content-owner from changes to the distribution network.

4.2. Use of non-deterministic DNS names in-protocol

A second pattern is for a control protocol to connect to a known HTTP end point. This is easily described in MUD. Within that control protocol references are made to additional content at other URLs. The values of those URLs do not fit any easily described pattern and may point at arbitrary names.
Those names are often within some third-party Content-Distribution-Network (CDN) system, or may be arbitrary names in a cloud-provider storage system such as Amazon S3 (such as [AmazonS3], or [Akamai]).

Since it is not possible to predict a name for where the content will be, it is not possible to include that into the MUD file.

This applies to the firmware update situation as well.

4.3. Use of a too inclusive DNS name

Some CDNs make all customer content at a single URL (such as s3.amazonaws.com). This seems to be ideal from a MUD point of view: a completely predictable URL. The problem is that a compromised device could then connect to any S3 bucket, potentially attacking other buckets.

Amazon has recognized the problems associated with this practice, and aims to change it to a virtual hosting model, as per [awss3virtualhosting].

The MUD ACLs provide only for permitting end points (hostnames and ports), but do not filter URLs (nor could filtering be enforced within HTTPS).

5. DNS privacy and outsourcing versus MUD controllers

[RFC7858] and [RFC8094] provide for DNS over TLS (DoT) and DNS over HTTPS (DoH). [I-D.ietf-dnsop-terminology-ter] details the terms. But, even with traditional DNS over Port-53 (Do53), it is possible to outsource DNS queries to other public services, such as those operated by Google, CloudFlare, Verisign, etc.

There are significant privacy issues with having IoT devices sending their DNS queries to an outside entity. Doing it over a secure transport (DoT/DoH) is clearly better than doing so on port 53. The providers of the secure resolver service will, however, still see the IoT device queries.

A described above in Section 3 the MUD controller needs to have access to the same resolver(s) as the IoT device. Use of the QuadX resolvers (such as Google's 8.8.8.8) at first seems to present less of a problem than use of some other less well known resolver. While any system may use QuadX, in most cases those services are massively replicated via anycast: there is no guarantee that a MUD controller will speak to the same instance, or get the same geographic anycast result.
6. Recommendations to IoT device manufacturer on MUD and DNS usage

Inclusion of a MUD file with IoT devices is operationally quite simple. It requires only a few small changes to the DHCP client code to express the MUD URL. It can even be done without code changes via the use of a QR code affixed to the packaging (see [I-D.richardson-mud-qrcode]).

The difficult part is determining what to put into the MUD file itself. There are currently tools that help with the definition and analysis of MUD files, see [mudmaker]. The remaining difficulty is now the semantic contents of what is in the MUD file. An IoT manufacturer must now spend some time reviewing what the network communications that their device does.

This document has discussed a number of challenges that occur relating to how DNS requests are made and resolved, and it is the goal of this section to make recommendations on how to modify IoT systems to work well with MUD.

6.1. Consistently use DNS

The first recommendation is to avoid using IP address literals in any protocol. Names should always be used.

6.2. Use primary DNS names controlled by the manufacturer

The second recommendation is to allocate and use names within zones controlled by the manufacturer. These names can be populated with an alias (see [RFC8499] section 2) that points to the production system. Ideally, a different name is used for each logical function, allowing for different rules in the MUD file to be enabled and disabled.

While it used to be costly to have a large number of aliases in a web server certificate, this is no longer the case. Wildcard certificates are also commonly available which allowed for an infinite number of possible names.
6.3. Use Content-Distribution Network with stable names

When aliases point to a Content-Distribution Network (CDN), prefer to use stable names that point to appropriately load balanced targets. CDNs that employ very low time-to-live (TTL) values for DNS make it harder for the MUD controller to get the same answer as the IoT Device. A CDN that always returns the same set of A and AAAA records, but permutes them to provide the best one first provides a more reliable answer.

6.4. Do not use geofenced names

Due the problems with different answers from different DNS servers, described above, a strong recommendation is to avoid using such things.

6.5. Prefer DNS servers learnt from DHCP/Route Advertisements

XXX - it has been suggested that this will not help, thus previous recommendation.

IoT Devices should prefer doing DNS to the network provided DNS servers. Whether this is restricted to Classic DNS (Do53) or also includes using DoT/DoH is a local decision, but a locally provided DoT server SHOULD be used, as recommended by [I-D.reddy-dprive-bootstrap-dns-server] and [I-D.peterson-doh-dhcp].

The ADD WG is currently only focusing on insecure discovery mechanisms like DHCP/RA [I-D.btw-add-home] and DNS based discovery mechanisms ([?{I-D.pauly-add-deer}]). Secure discovery of network provided DoH/DoT resolver is possible using the mechanisms discussed in [I-D.reddy-add-enterprise] section-4.

Use of public QuadX resolver instead of the provided DNS resolver, whether Do53, DoT or DoH is discouraged. Should the network provide such a resolver for use, then there is no reason not to use it, as the network operator has clearly thought about this.

Some manufacturers would like to have a fallback to using a public resolver to mitigate against local misconfiguration. There are a number of reasons to avoid this, or at least do this very carefully. The recommendation here is to do this only when the provided resolvers provide no answers to any queries at all, and do so repeatedly. The use of the operator provided resolvers SHOULD be retried on a periodic basis, and once they answer, there should be no further attempts to contact public resolvers.
Finally, the list of public resolvers that might be contacted MUST be listed in the MUD file as destinations that are to be permitted! This should include the port numbers (53, 853 for DoT, 443 for DoH) that will be used as well.

7. Privacy Considerations

The use of non-local DNS servers exposes the list of names resolved to a third parties, including passive eavesdroppers.

The use of DoT and DoH eliminates the minimizes threat from passive eavesdropped, but still exposes the list to the operator of the DoT or DoH server. There are additional methods, such as described by [I-D.pauly-dprive-oblivious-doh].

The use of unencrypted (Do53) requests to a local DNS server exposes the list to any internal passive eavesdroppers, and for some situations that may be significant, particularly if unencrypted WiFi is used. Use of Encrypted DNS connection to a local DNS recursive resolver is a preferred choice, assuming that the trust anchor for the local DNS server can be obtained, such as via [I-D.reddy-dprive-bootstrap-dns-server].

IoT devices that reach out to the manufacturer at regular intervals to check for firmware updates are informing passive eavesdroppers of the existence of a specific manufacturer’s device being present at the origin location.

Identifying the IoT device type empowers the attacker to launch targeted attacks to the IoT device (e.g., Attacker can advantage of the device vulnerability).

While possession of a Large (Kitchen) Appliance at a residence may be uninteresting to most, possession of intimate personal devices (e.g., "sex toys") may be a cause for embarrassment.

IoT device manufacturers are encouraged to find ways to anonymize their update queries. For instance, contracting out the update notification service to a third party that deals with a large variety of devices would provide a level of defense against passive eavesdropping. Other update mechanisms should be investigated, including use of DNSSEC signed TXT records with current version information. This would permit DoT or DoH to convey the update notification in a private fashion. This is particularly powerful if a local recursive DoT server is used, which then communicates using DoT over the Internet.
The more complex case of section Section 4.1 postulates that the version number needs to be provided to an intelligent agent that can decided the correct route to do upgrades. The current [I-D.ietf-suit-architecture] specification provides a wide variety of ways to accomplish the same thing without having to divulge the current version number.

The use of a publically specified firmware update protocol would also enhance privacy of IoT devices. In such a system the IoT device would never contact the manufacturer for version information or for firmware itself. Instead, details of how to query and where to get the firmware would be provided as a MUD extension, and a Enterprise-wide mechanism would retrieve firmware, and then distribute it internally. Aside from the bandwidth savings of downloading the firmware only once, this also makes the number of devices active confidential, and provides some evidence about which devices have been upgraded and which ones might still be vulnerable. (The unpatched devices might be lurking, powered off, lost in a closet)

8. Security Considerations

This document deals with conflicting Security requirements:

1. devices which an operator wants to manage using [RFC8520]

2. requirements for the devices to get access to network resources that may be critical to their continued safe operation.

This document takes the view that the two requirements do not need to be in conflict, but resolving the conflict requires some advance planning by all parties.

9. References

9.1. Normative References


[I-D.ietf-suit-architecture]

[I-D.peterson-doh-dhcp]

[I-D.reddy-dprive-bootstrap-dns-server]


9.2. Informative References


Appendix A. Appendices

Authors’ Addresses

Michael Richardson
Sandelman Software Works

Email: mcr+ietf@sandelman.ca

Wei Pan
Huawei Technologies

Email: william.panwei@huawei.com
PCAP Capture File Format
draft-ietf-opsawg-pcap-00

Abstract

This document describes the format used by the libpcap library to record captured packets to a file. Programs using the libpcap library to read and write those files, and thus reading and writing files in that format, include tcpdump.

Discussion Venues

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

Discussion of this document takes place on the OPSAWG Working Group mailing list (opsawg@ietf.org), which is archived at https://mailarchive.ietf.org/arch/browse/opsawg/.

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

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on 28 April 2022.
1. Introduction

In the late 1980’s, Van Jacobson, Steve McCanne, and others at the Network Research Group at Lawrence Berkeley National Laboratory developed the tcpdump program to capture and dissect network traces. The code to capture traffic, using low-level mechanisms in various operating systems, and to read and write network traces to a file was later put into a library named libpcap.

This document describes the format used by tcpdump, and other programs using libpcap, to read and write network traces.
2. 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.

3. General File Structure

A capture file begins with a File Header, followed by zero or more Packet Records, one per packet.

All fields in the File Header and in Packet Records will always be saved according to the characteristics (little endian / big endian) of the capturing machine. This refers to all the fields that are saved as numbers and that span over two or more octets.

The approach of having the file saved in the native format of the generating host is more efficient because it avoids translation of data when reading / writing on the host itself, which is the most common case when generating/processing capture captures.

The packets are shown in traditional IETF diagram, with the bits numbered from the left to the right. The bit numbering does not reflect the binary value position, as IETF protocols are traditionally in big-endian network-byte order. The most significant bit is therefore on the left in this diagram as if the file is being stored on a big-endian system.

4. File Header

The File Header has the following format:
Figure 1: File Header

The File Header length is 24 octets.

The meaning of the fields in the File Header is:

Magic Number (32 bits): an unsigned magic number, whose value is either the hexadecimal number 0xA1B2C3D4 or the hexadecimal number 0xA1B23C4D.

If the value is 0xA1B2C3D4, time stamps in Packet Records (see Figure 2) are in seconds and microseconds; if it is 0xA1B23C4D, time stamps in Packet Records are in seconds and nanoseconds.

These numbers can be used to distinguish sessions that have been saved on little-endian machines from the ones saved on big-endian machines, and to heuristically identify pcap files.

Major Version (16 bits): an unsigned value, giving the number of the current major version of the format. The value for the current version of the format is 2. This value should change if the format changes in such a way that code that reads the new format could not read the old format (i.e., code to read both formats would have to check the version number and use different code paths for the two formats) and code that reads the old format could not read the new format.

Minor Version (16 bits): an unsigned value, giving the number of the
current minor version of the format. The value is for the current version of the format is 4. This value should change if the format changes in such a way that code that reads the new format could read the old format without checking the version number but code that reads the old format could not read all files in the new format.

Reserved1 (32 bits): not used - SHOULD be filled with 0 by pcap file writers, and MUST be ignored by pcap file readers. This value was documented by some older implementations as "gmt to local correction". Some older pcap file writers stored non-zero values in this field.

Reserved2 (32 bits): not used - SHOULD be filled with 0 by pcap file writers, and MUST be ignored by pcap file readers. This value was documented by some older implementations as "accuracy of timestamps". Some older pcap file writers stored non-zero values in this field.

SnapLen (32 bits): an unsigned value indicating the maximum number of octets captured from each packet. The portion of each packet that exceeds this value will not be stored in the file. This value MUST NOT be zero; if no limit was specified, the value should be a number greater than or equal to the largest packet length in the file.

LinkType (16 bits): a 16-bit unsigned value that defines the link layer type of packets in the file. This field is defined in the Section 8.2 IANA registry.

Frame Cyclic Sequence (FCS) present (4 bits): if the "f" bit is set, then the 3 FCS bits provide the number of 16-bit (2 byte) words of FCS that are appended to each packet.

valid values are between 0 and 7, with ethernet typically having a length of 4 bytes, or a value of 2.

The bits marked as zero MUST be set to zero by pcap writers, and MUST be ignored by pcap readers.

5. Packet Record

A Packet Record is the standard container for storing the packets coming from the network.
Figure 2: Packet Record

The Packet Header length is 16 octets.

The meaning of the fields in the Packet Record is:

Timestamp (Seconds) and Timestamp (Microseconds or nanoseconds): seconds and fraction of a seconds values of a timestamp.

The seconds value is a 32-bit unsigned integer that represents the number of seconds that have elapsed since 1970-01-01 00:00:00 UTC, and the microseconds or nanoseconds value represents the number of microseconds or nanoseconds that have elapsed since that seconds.

Whether the value represents microseconds or nanoseconds is specified by the magic number in the File Header.

Captured Packet Length (32 bits): an unsigned value that indicates the number of octets captured from the packet (i.e. the length of the Packet Data field). It will be the minimum value among the Original Packet Length and the snapshot length for the interface (SnapLen, defined in Figure 1).

Original Packet Length (32 bits): an unsigned value that indicates the actual length of the packet when it was transmitted on the network. It can be different from the Captured Packet Length if the packet has been truncated by the capture process.

Packet Data: the data coming from the network, including link-layer
headers. The actual length of this field is Captured Packet Length. The format of the link-layer headers depends on the LinkType field specified in the file header (see Figure 1) and it is specified in the entry for that format in [LINKTYPES].

6. Recommended File Name Extension: .pcap

The recommended file name extension for the "PCAP Capture File Format" specified in this document is ".pcap".

On Windows and macOS, files are distinguished by an extension to their filename. Such an extension is technically not actually required, as applications should be able to automatically detect the pcap file format through the "magic bytes" at the beginning of the file, as some other UN*X desktop environments do. However, using name extensions makes it easier to work with files (e.g. visually distinguish file formats) so it is recommended - though not required - to use .pcap as the name extension for files following this specification.

Please note: To avoid confusion (such as the current usage of .cap for a plethora of different capture file formats) file name extensions other than .pcap should be avoided.

There is new work to create the PCAP Next Generation capture File Format (see [I-D.tuexen-opsawg-pcapng]). The new file format is not compatible with this specification, but many programs read both transparently. Files of that type will usually start with a Section Header Block, with a magic number of 0x0A0D0D0A.

7. Security Considerations

TBD.

8. IANA Considerations

This document requires the following IANA actions:

8.1. Media-Type Registry

This section registers the media types in the "Media Types" registry. These media types are used to indicate that the content is packet capture as described in this document.

8.1.1. application/pcap
Type name:  application
Subtype name:  pcap
Required parameters:  none
Optional parameters:  none
Encoding considerations:  PCAP files contain network packets
Security considerations:  See Security Considerations, Section
Interoperability considerations:  The format is designed to be broadly interoperable.
Published specification:  THIS RFC.
Applications that use this media type: tcpdump, wireshark, others.
Additional information:
  Magic number(s): 0xA1B2C3D4, and 0xA1B23C4D in both endian orders
  File extension(s): .pcap
  Macintosh file type code(s):  none
Person & email address to contact for further information: The Tcpdump Group, www.tcpdump.org
Intended usage:  LIMITED
Restrictions on usage:  NONE
Author:  Guy Harris and Michael Richardson
Change controller:  The Tcpdump Group
Provisional registration? (standards tree only):  NO

8.2.  LinkType Registry

IANA is requested to create a new Registry entitled: "The PCAP Registry", and within that Registry to create a table called: "PCAP LinkType List".

The LinkType Registry is a table of 16-bit numbers. The Registry has three sections with different [RFC8126] rules:

* values from 0 to 32767 are marked as Specification Required.
* values from 32768 to 65000 are marked as First-Come First-Served.
* values from 65000 to 65535 are marked as Private Use.

The Registry has four columns: the symbolic name (LINKTYPE_something), the integer value, a very short description, and the document/requestor reference.

The Registry shall be populated as follows in the table below. In each case here, the reference should be http://www.tcpdump.org/linktypes.html, which is not repeated.

The initial value of table is base upon the Link type list maintained by libpcap, and published on the tcpdump.org web site as http://www.tcpdump.org/linktypes.html.
There is often an associated DLT value which are often identical in value, but not universally so. DLT values are associated with specific operation system captures, and are operating system specific.

<table>
<thead>
<tr>
<th>LINKTYPE name</th>
<th>LINKTYPE value</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINKTYPE_NULL</td>
<td>0</td>
<td>BSD loopback encapsulation</td>
</tr>
<tr>
<td>LINKTYPE_ETHERNET</td>
<td>1</td>
<td>IEEE 802.3 Ethernet</td>
</tr>
<tr>
<td>LINKTYPE_EXP_ETHERNET</td>
<td>2</td>
<td>Xerox experimental 3Mb Ethernet</td>
</tr>
<tr>
<td>LINKTYPE_AX25</td>
<td>3</td>
<td>AX.25 packet</td>
</tr>
<tr>
<td>LINKTYPE_PRONET</td>
<td>4</td>
<td>Reserved for PRONET</td>
</tr>
<tr>
<td>LINKTYPE_CHAOS</td>
<td>5</td>
<td>Reserved for MIT CHAOSNET</td>
</tr>
<tr>
<td>LINKTYPE_IEEE802_5</td>
<td>6</td>
<td>IEEE 802.5 Token Ring</td>
</tr>
<tr>
<td>LINKTYPE_ARCNET_BSD</td>
<td>7</td>
<td>ARCNET Data Packets with BSD encapsulation</td>
</tr>
<tr>
<td>LINKTYPE_SLIP</td>
<td>8</td>
<td>SLIP, w/ LINKTYPE_SLIP header.</td>
</tr>
<tr>
<td>LINKTYPE_PPP</td>
<td>9</td>
<td>PPP, as per RFC 1661/RFC 1662</td>
</tr>
<tr>
<td>not to be used</td>
<td>11-49</td>
<td>Do not use these values</td>
</tr>
<tr>
<td>LINKTYPE_PPP_HDLC</td>
<td>50</td>
<td>PPP in HDLC-like framing, as per RFC 1662</td>
</tr>
<tr>
<td>LINKTYPE_PPPEther</td>
<td>51</td>
<td>PPPoE; per RFC 2516</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------</td>
<td>---------------------</td>
</tr>
<tr>
<td>not to be used</td>
<td>52-98</td>
<td>Do not use these</td>
</tr>
<tr>
<td></td>
<td></td>
<td>values</td>
</tr>
<tr>
<td>LINKTYPE_SYMANTEC_FIREWALL</td>
<td>99</td>
<td>Reserved for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Symantec Enterprise</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Firewall</td>
</tr>
<tr>
<td>LINKTYPE_ATM_RFC1483</td>
<td>100</td>
<td>RFC 1483 LLC/SNAP-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>encapsulated ATM</td>
</tr>
<tr>
<td>LINKTYPE_RAW</td>
<td>101</td>
<td>Raw IP; begins with</td>
</tr>
<tr>
<td></td>
<td></td>
<td>an IPv4 or IPv6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>header</td>
</tr>
<tr>
<td>LINKTYPE_SLIP_BSDOS</td>
<td>102</td>
<td>Reserved for BSD/OS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SLIP BPF header</td>
</tr>
<tr>
<td>LINKTYPE_PPP_BSDOS</td>
<td>103</td>
<td>Reserved for BSD/OS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PPP BPF header</td>
</tr>
<tr>
<td>LINKTYPE_C_HDLC</td>
<td>104</td>
<td>Cisco PPP with HDLC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>framing, as per</td>
</tr>
<tr>
<td></td>
<td></td>
<td>section 4.3.1 of RFC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1547</td>
</tr>
<tr>
<td>LINKTYPE_IEEE802_11</td>
<td>105</td>
<td>IEEE 802.11 wireless</td>
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<td></td>
<td>LAN.</td>
</tr>
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<td>LINKTYPE_ATM_CLIP</td>
<td>106</td>
<td>ATM Classical IP,</td>
</tr>
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<td></td>
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<td>with no header</td>
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<td></td>
<td></td>
<td>preceding IP</td>
</tr>
<tr>
<td>LINKTYPE_FRELAY</td>
<td>107</td>
<td>Frame Relay LAPF</td>
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<tr>
<td></td>
<td></td>
<td>frames</td>
</tr>
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<td>LINKTYPE_LOOP</td>
<td>108</td>
<td>OpenBSD loopback</td>
</tr>
<tr>
<td></td>
<td></td>
<td>encapsulation</td>
</tr>
<tr>
<td>LINKTYPE_ENC</td>
<td>109</td>
<td>Reserved for OpenBSD</td>
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<tr>
<td></td>
<td></td>
<td>IPSEC encapsulation</td>
</tr>
<tr>
<td>LINKTYPE_LANE8023</td>
<td>110</td>
<td>Reserved for ATM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LANE + 802.3</td>
</tr>
<tr>
<td>LINKTYPE_HIPPI</td>
<td>111</td>
<td>Reserved for NetBSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HIPPI</td>
</tr>
<tr>
<td>LINKTYPE</td>
<td>Value</td>
<td>Description</td>
</tr>
<tr>
<td>------------------</td>
<td>-------</td>
<td>--------------------------------------------------</td>
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<td>LINKTYPE_HDLC</td>
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<td>Reserved for NetBSD HDLC framing</td>
</tr>
<tr>
<td>LINKTYPE_LINUX_SLL</td>
<td>113</td>
<td>Linux &quot;cooked&quot; capture encapsulation</td>
</tr>
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<td>LINKTYPE_LTALK</td>
<td>114</td>
<td>Apple LocalTalk</td>
</tr>
<tr>
<td>LINKTYPE_ECONET</td>
<td>115</td>
<td>Reserved for Acorn Econet</td>
</tr>
<tr>
<td>LINKTYPE_IPFILTER</td>
<td>116</td>
<td>Reserved for OpenBSD ipfilter</td>
</tr>
<tr>
<td>LINKTYPE_PFLOG</td>
<td>117</td>
<td>OpenBSD pflog; &quot;struct pfloghdr&quot; structure</td>
</tr>
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<td>LINKTYPE_CISCO_IOS</td>
<td>118</td>
<td>Reserved for Cisco-internal use</td>
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<td>LINKTYPE_IEEE802_11_PRISM</td>
<td>119</td>
<td>Prism monitor mode</td>
</tr>
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<td>LINKTYPE_IEEE802_11_AIRONET</td>
<td>120</td>
<td>Reserved for 802.11 + FreeBSD Aironet radio metadata</td>
</tr>
<tr>
<td>LINKTYPE_HHDLC</td>
<td>121</td>
<td>Reserved for Siemens HiPath HDLC</td>
</tr>
<tr>
<td>LINKTYPE_IP_OVER_FC</td>
<td>122</td>
<td>RFC 2625 IP-over-Fibre Channel</td>
</tr>
<tr>
<td>LINKTYPE_SUNATM</td>
<td>123</td>
<td>ATM traffic, / per SunATM devices</td>
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<tr>
<td>LINKTYPE_RIO</td>
<td>124</td>
<td>Reserved for RapidIO</td>
</tr>
<tr>
<td>LINKTYPE_PCI_EXP</td>
<td>125</td>
<td>Reserved for PCI Express</td>
</tr>
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<td>LINKTYPE_AURORA</td>
<td>126</td>
<td>Reserved for Xilinx Aurora link layer</td>
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<tr>
<td>LINKTYPE_IEEE802_11_RADIOTAP</td>
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<td>Radiotap</td>
</tr>
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</table>
header[Radiotap], followed by an 802.11 header

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<tr>
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</tr>
</thead>
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<tr>
<td>LINKTYPE_ARCNET_LINUX</td>
<td>129</td>
<td>ARCNET Data Packets, per RFC 1051 frames w/variations</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_MLPPP</td>
<td>130</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_MLFR</td>
<td>131</td>
<td>Reserved for Juniper Networks</td>
</tr>
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<td>LINKTYPE_JUNIPER_ES</td>
<td>132</td>
<td>Reserved for Juniper Networks</td>
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<td>LINKTYPE_JUNIPER_GGSN</td>
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</tr>
<tr>
<td>LINKTYPE_JUNIPER_MFR</td>
<td>134</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_ATM2</td>
<td>135</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_SERVICES</td>
<td>136</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_ATM1</td>
<td>137</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_APPLE_IP_OVER_IEEE1394</td>
<td>138</td>
<td>Apple IP-over-IEEE 1394 cooked header</td>
</tr>
<tr>
<td>LINKTYPE_MTP2_WITH_PHDR</td>
<td>139</td>
<td>Signaling System 7 (SS7) Message Transfer Part Level ITU-T Q.703</td>
</tr>
<tr>
<td>LINKTYPE_MTP2</td>
<td>140</td>
<td>SS7 Level 2, Q.703</td>
</tr>
<tr>
<td>LINKTYPE_MTP3</td>
<td>141</td>
<td>SS7 Level 3, Q.704</td>
</tr>
<tr>
<td>LINKTYPE_SCCP</td>
<td>142</td>
<td>SS7 Control Part,</td>
</tr>
<tr>
<td>LINKTYPE_DOCSIS</td>
<td>143</td>
<td>DOCSIS MAC frames, DOCSIS 3.1</td>
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<tr>
<td>LINKTYPE_LINUX_IRDA</td>
<td>144</td>
<td>Linux-IrDA packets w/ LINKTYPE_LINUX_IRDA header</td>
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<tr>
<td>LINKTYPE_IBM_SP</td>
<td>145</td>
<td>Reserved for IBM SP switch</td>
</tr>
<tr>
<td>LINKTYPE_IBM_SN</td>
<td>146</td>
<td>Reserved for IBM Next Federation switch</td>
</tr>
<tr>
<td>LINKTYPE_RESERVED_01</td>
<td>147</td>
<td>For private use</td>
</tr>
<tr>
<td>LINKTYPE_RESERVED_02</td>
<td>148</td>
<td>For private use</td>
</tr>
<tr>
<td>LINKTYPE_RESERVED_03</td>
<td>149</td>
<td>For private use</td>
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<tr>
<td>LINKTYPE_RESERVED_04</td>
<td>150</td>
<td>For private use</td>
</tr>
<tr>
<td>LINKTYPE_RESERVED_05</td>
<td>151</td>
<td>For private use</td>
</tr>
<tr>
<td>LINKTYPE_RESERVED_06</td>
<td>152</td>
<td>For private use</td>
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<tr>
<td>LINKTYPE_RESERVED_07</td>
<td>153</td>
<td>For private use</td>
</tr>
<tr>
<td>LINKTYPE_RESERVED_08</td>
<td>154</td>
<td>For private use</td>
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<tr>
<td>LINKTYPE_RESERVED_09</td>
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<td>For private use</td>
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<td>LINKTYPE_RESERVED_10</td>
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<td>For private use</td>
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<tr>
<td>LINKTYPE_RESERVED_11</td>
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<td>LINKTYPE_RESERVED_12</td>
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<td>For private use</td>
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<tr>
<td>LINKTYPE_RESERVED_13</td>
<td>159</td>
<td>For private use</td>
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<tr>
<td>LINKTYPE_RESERVED_14</td>
<td>160</td>
<td>For private use</td>
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<tr>
<td>LINKTYPE_RESERVED_15</td>
<td>161</td>
<td>For private use</td>
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<tr>
<td>LINKTYPE</td>
<td>Value</td>
<td>Description</td>
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<tr>
<td>LINKTYPE_RESERVED_16</td>
<td>162</td>
<td>For private use</td>
</tr>
<tr>
<td>LINKTYPE_IEEE802_11_AVS</td>
<td>163</td>
<td>AVS header[AVS], followed by an 802.11 header</td>
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<tr>
<td>LINKTYPE_JUNIPER_MONITOR</td>
<td>164</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_BACNET_MS_TP</td>
<td>165</td>
<td>BACnet MS/TP frames, per 9.3 MS/TP Frame Format ANSI 135</td>
</tr>
<tr>
<td>LINKTYPE_PPP_PPPD</td>
<td>166</td>
<td>PPP in HDLC-like encapsulation, like LINKTYPE_PPP_HDLC, different stuffing</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_PPPOE</td>
<td>167</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_PPPOE_ATM</td>
<td>168</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_GPRS_LLC</td>
<td>169</td>
<td>General Packet Radio Service Logical Link Control, as per 3GPP TS 04.64</td>
</tr>
<tr>
<td>LINKTYPE_GPF_T</td>
<td>170</td>
<td>Transparent-mapped generic framing procedure, as specified by ITU-T Recommendation G.7041/Y.1303</td>
</tr>
<tr>
<td>LINKTYPE_GPF_F</td>
<td>171</td>
<td>Frame-mapped generic framing procedure, as specified by ITU-T Recommendation G.7041/Y.1303</td>
</tr>
<tr>
<td>LINKTYPE_GCOM_T1E1</td>
<td>172</td>
<td>Reserved for Gcom T1/E1 line monitoring equipment</td>
</tr>
<tr>
<td>LINKTYPE_GCOM_SERIAL</td>
<td>173</td>
<td>Reserved for Gcom</td>
</tr>
<tr>
<td>LINKTYPE</td>
<td>Value</td>
<td>Description</td>
</tr>
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</tr>
<tr>
<td>LINKTYPE_JUNIPER_PIC_PEER</td>
<td>174</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_ERF_ETH</td>
<td>175</td>
<td>Endace ERF header followed by 802.3 Ethernet</td>
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<tr>
<td>LINKTYPE_ERF_POS</td>
<td>176</td>
<td>Endace ERF header followed by Packet-over-SONET</td>
</tr>
<tr>
<td>LINKTYPE_LINUX_LAPD</td>
<td>177</td>
<td>Link Access Procedures on the D Channel (LAPD) frames, as specified by ITU-T Recommendation Q.920 and ITU-T Recommendation Q.921, captured via vISDN, with a LINKTYPE_LINUX_LAPD header, followed by the Q.921 frame, starting with the address field.</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_ETHER</td>
<td>178</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_PPP</td>
<td>179</td>
<td>Reserved for Juniper Networks</td>
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<tr>
<td>LINKTYPE_JUNIPER_FRELAY</td>
<td>180</td>
<td>Reserved for Juniper Networks</td>
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<tr>
<td>LINKTYPE_JUNIPER_CHDLC</td>
<td>181</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_MFR</td>
<td>182</td>
<td>FRF.16.1 Multi-Link Frame Relay frames, beginning with an FRF.12 Interface fragmentation format fragmentation</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_VP</td>
<td>182</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_A653_ICM</td>
<td>185</td>
<td>Reserved for Arinc 653 Interpartition Communication messages</td>
</tr>
<tr>
<td>LINKTYPE_USB_FREEBSD</td>
<td>186</td>
<td>USB packets, beginning with a FreeBSD USB header</td>
</tr>
<tr>
<td>LINKTYPE_BLUETOOTH_HCI_H4</td>
<td>187</td>
<td>Bluetooth HCI UART transport layer; the frame contains an HCI packet indicator byte, as specified by the UART Transport Layer portion of the most recent Bluetooth Core specification, followed by an HCI packet of the specified packet type, as specified by the Host Controller Interface Functional Specification portion of the most recent Bluetooth Core Specification.</td>
</tr>
<tr>
<td>LINKTYPE_IEEE802_16_MAC_CPS</td>
<td>188</td>
<td>Reserved for IEEE 802.16 MAC Common Part Sublayer</td>
</tr>
<tr>
<td>LINKTYPE_USB_LINUX</td>
<td>189</td>
<td>USB packets, beginning with a Linux USB header, as specified by the struct usbmon_packet in the Documentation/usb/usbmon.txt file in</td>
</tr>
</tbody>
</table>
Only the first 48 bytes of that header are present. All fields in the header are in host byte order. When performing a live capture, the host byte order is the byte order of the machine on which the packets are captured. When reading a pcap file, the byte order is the byte order for the file, as specified by the file’s magic number; when reading a pcapng file, the byte order is the byte order for the section of the pcapng file, as specified by the Section Header Block.

<table>
<thead>
<tr>
<th>LINKTYPE_CAN20B</th>
<th>190</th>
<th>Reserved for Controller Area Network (CAN) v. 2.0B packets</th>
</tr>
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<tbody>
<tr>
<td>LINKTYPE_IEEE802_15_4_LINUX</td>
<td>191</td>
<td>IEEE 802.15.4, with address fields padded, as is done by Linux drivers</td>
</tr>
<tr>
<td>LINKTYPE_PPI</td>
<td>192</td>
<td>Per-Packet Information information, as specified by the Per-Packet Information Header Specification, followed by a packet</td>
</tr>
</tbody>
</table>
with the LINKTYPE_ value specified by the pph_dlt field of that header.

<table>
<thead>
<tr>
<th>Link Type</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINKTYPE_IEEE802_16_MAC_CFS_RADIO</td>
<td>193</td>
<td>Reserved for 802.16 MAC Common Part Sublayer plus radio header</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_ISM</td>
<td>194</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_IEEE802_15_4_WITHFCS</td>
<td>195</td>
<td>IEEE 802.15.4 Low-Rate Wireless Networks, with each packet having the FCS at the end of the frame.</td>
</tr>
<tr>
<td>LINKTYPE_SITA</td>
<td>196</td>
<td>Various link-layer types, with a pseudo-header, for SITA</td>
</tr>
<tr>
<td>LINKTYPE_ERF</td>
<td>197</td>
<td>Various link-layer types, with a pseudo-header, for Endace DAG cards; encapsulates Endace ERF records.</td>
</tr>
<tr>
<td>LINKTYPE_RAIF1</td>
<td>198</td>
<td>Reserved for Ethernet packets captured from a u10 Networks board</td>
</tr>
<tr>
<td>LINKTYPE_IPMB_KONTRON</td>
<td>199</td>
<td>Reserved for IPMB packet for IPMI, with a 2-byte header</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_ST</td>
<td>200</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_BLUETOOTH_HCI_H4_WITH_PHDR</td>
<td>201</td>
<td>Bluetooth HCI UART transport layer; the frame contains a 4-byte direction</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>LINKTYPE_AX25_KISS</th>
<th>202</th>
<th>AX.25 packet, with a 1-byte KISS header containing a type indicator.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINKTYPE_LAPD</td>
<td>203</td>
<td>Link Access Procedures on the D Channel (LAPD) frames, as specified by ITU-T Recommendation Q.920 and ITU-T Recommendation Q.921, starting with the address field, with no pseudo-header.</td>
</tr>
<tr>
<td>LINKTYPE_PPP_WITH_DIR</td>
<td>204</td>
<td>PPP, as per RFC 1661 and RFC 1662, preceded with a one-byte pseudo-header with a zero value meaning received by this host and a non-zero value meaning sent by this host; if the first 2 bytes are 0xff and 0x03, it’s PPP in HDLC-like framing, with the PPP header following those two bytes, otherwise it’s PPP without framing, and the packet begins with the PPP header. The data in the frame is not octet-stuffed or bit-stuffed.</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LINKTYPE_C_HDLC_WITH_DIR</td>
<td>205</td>
<td>Cisco PPP with HDLC framing, as per section 4.3.1 of RFC 1547, preceded with a one-byte pseudo-header with a zero value meaning received by this host and a non-zero value meaning sent by this host.</td>
</tr>
<tr>
<td>LINKTYPE_FRELAY_WITH_DIR</td>
<td>206</td>
<td>Frame Relay LAPF frames, beginning with a one-byte pseudo-header with a zero value meaning received by this host (DCE-&gt;DTE) and a non-zero value meaning sent by this host (DTE-&gt;DCE), followed by an ITU-T Recommendation Q.922.</td>
</tr>
<tr>
<td>LINKTYPE_LAPB_WITH_DIR</td>
<td>207</td>
<td>LAPF header starting with the address field, and without an FCS at the end of the frame.</td>
</tr>
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</tr>
<tr>
<td>LINKTYPE_IPMB_LINUX</td>
<td>209</td>
<td>Link Access Procedure, Balanced (LAPB), as specified by ITU-T Recommendation X.25, preceded with a one-byte pseudo-header with a zero value meaning received by this host (DCE-&gt;DTE) and a non-zero value meaning sent by this host (DTE-&gt;DCE).</td>
</tr>
<tr>
<td>LINKTYPE_FLEXRAY</td>
<td>210</td>
<td>Reserved for FlexRay automotive bus</td>
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<tr>
<td>LINKTYPE_MOST</td>
<td>211</td>
<td>Reserved for Media Oriented Systems Transport (MOST) bus</td>
</tr>
<tr>
<td>LINKTYPE_LIN</td>
<td>212</td>
<td>Reserved for Local Interconnect Network (LIN) bus for vehicle networks</td>
</tr>
<tr>
<td>LINKTYPE_X2E_SERIAL</td>
<td>213</td>
<td>Reserved for X2E serial line captures</td>
</tr>
<tr>
<td>LINKTYPE_X2E_XORAYA</td>
<td>214</td>
<td>Reserved for X2E Xoraya data loggers</td>
</tr>
<tr>
<td>LINKTYPE_IEEE802_15_4_NONASK_PHY</td>
<td>215</td>
<td>IEEE 802.15.4 Low-Rate Wireless Networks, with each packet having the FCS at the end of the frame, and with the PHY-level data for the O-QPSK, BPSK, GFSK, MSK, and RCC DSS BPSK PHYs (4 octets of 0 as preamble, one octet of SFD, one octet of frame length + reserved bit) preceding the MAC-layer data (starting with the frame control field).</td>
</tr>
<tr>
<td>LINKTYPE_LINUX_EVDEV</td>
<td>216</td>
<td>Reserved for Linux evdev messages</td>
</tr>
<tr>
<td>LINKTYPE_GSMTAP_UM</td>
<td>217</td>
<td>Reserved for GSM Um interface, with gsmtap header</td>
</tr>
<tr>
<td>LINKTYPE_GSMTAP_ABIS</td>
<td>218</td>
<td>Reserved for GSM Abis interface, with gsmtap header</td>
</tr>
<tr>
<td>LINKTYPE_MPLS</td>
<td>219</td>
<td>MPLS packets with MPLS label as the header</td>
</tr>
<tr>
<td>LINKTYPE_USB_LINUX_MMAPPED</td>
<td>220</td>
<td>USB packets, beginning with a Linux USB header, as specified by the struct usbmon_packet in the Documentation/usb/usbmon.txt file in the Linux source tree. All 64 bytes of the header are present. All fields in the header are in</td>
</tr>
</tbody>
</table>
When performing a live capture, the host byte order is the byte order of the machine on which the packets are captured. When reading a pcap file, the byte order is the byte order for the file, as specified by the file’s magic number; when reading a pcapng file, the byte order is the byte order for the section of the pcapng file, as specified by the Section Header Block. For isochronous transfers, the ndesc field specifies the number of isochronous descriptors that follow.

- **LINKTYPE_DECT**: 221 Reserved for DECT packets, with a pseudo-header
- **LINKTYPE_AOS**: 222 Reserved for OS Space Data Link Protocol
- **LINKTYPE_WIhart**: 223 Reserved for Wireless HART (Highway Addressable Remote Transducer)
- **LINKTYPE_FC_2**: 224 Fibre Channel FC-2 frames, beginning with a Frame_Header.
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<thead>
<tr>
<th>Link Type</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINKTYPE_FC_2_WITH_FRAME_DELIMS</td>
<td>225</td>
<td>Fibre Channel FC-2 frames, beginning an encoding of the SOF, followed by a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frame Header, and ending with an encoding of the SOF. The encodings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>represent the frame delimiters as 4-byte sequences representing the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>corresponding ordered sets, with K28.5 represented as 0xBC, and the D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>symbols as the corresponding byte values; for example, SOFi2, which is</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K28.5 - D21.5 - D1.2 - D21.2, is represented as 0xBC 0xB5 0x55 0x55.</td>
</tr>
<tr>
<td>LINKTYPE_IPNET</td>
<td>226</td>
<td>Solaris ipnet pseudo-header, followed by an IPv4 or IPv6 datagram.</td>
</tr>
<tr>
<td>LINKTYPE_CAN_SOCKETCAN</td>
<td>227</td>
<td>CAN (Controller Area Network) frames, with a pseudo-header followed by the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>frame payload.</td>
</tr>
<tr>
<td>LINKTYPE_IPV4</td>
<td>228</td>
<td>Raw IPv4; the packet begins with an IPv4 header.</td>
</tr>
<tr>
<td>LINKTYPE_IPV6</td>
<td>229</td>
<td>Raw IPv6; the packet begins with an IPv6 header.</td>
</tr>
<tr>
<td>LINKTYPE_IEEE802_15_4_NOFCS</td>
<td>230</td>
<td>IEEE 802.15.4 Low-Rate Wireless Network, without the FCS at the end of</td>
</tr>
<tr>
<td>LINKTYPE_DBUS</td>
<td>231</td>
<td>Raw D-Bus messages, starting with the endianness flag, followed by the message type, etc., but without the authentication handshake before the message sequence.</td>
</tr>
<tr>
<td>--------------------------------</td>
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<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_VS</td>
<td>232</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_SRX_E2E</td>
<td>233</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_FIBRECHANNEL</td>
<td>234</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_DVB_CI</td>
<td>235</td>
<td>DVB-CI (DVB Common Interface for communication between a PC Card module and a DVB receiver), with the message format specified by the PCAP format for DVB-CI specification</td>
</tr>
<tr>
<td>LINKTYPE_MUX27010</td>
<td>236</td>
<td>Variant of 3GPP TS 27.010 multiplexing protocol (similar to, but not the same as, 27.010).</td>
</tr>
<tr>
<td>LINKTYPE_STANAG_5066_D_PDU</td>
<td>237</td>
<td>D_PDUs as described by NATO standard STANAG 5066, starting with the synchronization sequence, and including both header and data CRCs. The current version of STANAG</td>
</tr>
<tr>
<td>LINKTYPE_JUNIPER_ATM_CEMIC</td>
<td>238</td>
<td>Reserved for Juniper Networks</td>
</tr>
<tr>
<td>LINKTYPE_NFLOG</td>
<td>239</td>
<td>Linux netlink NETLINK NFLOG socket log messages.</td>
</tr>
<tr>
<td>LINKTYPE_NETANALYZER</td>
<td>240</td>
<td>Pseudo-header for Hilscher Gesellschaft fuer Systemautomation mbH netANALYZER devices, followed by an Ethernet frame, beginning with the MAC header and ending with the FCS.</td>
</tr>
<tr>
<td>LINKTYPE_NETANALYZER_TRANSPARENT</td>
<td>241</td>
<td>Pseudo-header for Hilscher Gesellschaft fuer Systemautomation mbH netANALYZER devices, followed by an Ethernet frame, beginning with the preamble, SFD, and MAC header, and ending with the FCS.</td>
</tr>
<tr>
<td>LINKTYPE_IPOIB</td>
<td>242</td>
<td>IP-over-InfiniBand, as specified by RFC 4391 section 6</td>
</tr>
<tr>
<td>LINKTYPE_MPEG_2_TS</td>
<td>243</td>
<td>MPEG-2 Transport Stream transport packets, as specified by ISO 13818-1/ ITU-T Recommendation H.222.0 (see table</td>
</tr>
<tr>
<td>LINKTYPE_NAME</td>
<td>CODE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>--------------------</td>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>LINKTYPE_NG40</td>
<td>244</td>
<td>Pseudo-header for (\text{ng}4\text{T GmbH}'s UMTS Iub/Iur-over-ATM and Iub/Iur-over-IP format as used by their ng40 protocol tester}, followed by frames for the Frame Protocol as specified by 3GPP TS 25.427 for dedicated channels and 3GPP TS 25.435 for common/shared channels in the case of ATM AAL2 or UDP traffic, by SSCOP packets as specified by ITU-T Recommendation Q.2110 for ATM AAL5 traffic, and by NBAP packets for SCTP traffic.</td>
</tr>
<tr>
<td>LINKTYPE_NFC_LLCP</td>
<td>245</td>
<td>Pseudo-header for NFC LLCP packet captures, followed by frame data for the LLCP Protocol as specified by NFCForum-TS-LLCP_1.1</td>
</tr>
<tr>
<td>LINKTYPE_PFSYNC</td>
<td>246</td>
<td>Reserved for pfsync output</td>
</tr>
<tr>
<td>LINKTYPE_INFINIBAND</td>
<td>247</td>
<td>Raw InfiniBand frames, starting with the Local Routing Header, as specified in Chapter 5 Data packet format of InfiniBand[TM] Architectural</td>
</tr>
<tr>
<td>LINKTYPE_SCTP</td>
<td>248</td>
<td>SCTP packets, as defined by RFC 4960, with no lower-level protocols such as IPv4 or IPv6.</td>
</tr>
<tr>
<td>---------------------</td>
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<td>-------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LINKTYPE_USBPCAP</td>
<td>249</td>
<td>USB packets, beginning with a USBPcap header</td>
</tr>
<tr>
<td>LINKTYPE_RTAC_SERIAL</td>
<td>250</td>
<td>Serial-line packet header for the Schweitzer Engineering Laboratories RTAC product, followed by a payload for one of a number of industrial control protocols.</td>
</tr>
<tr>
<td>LINKTYPE_BLUETOOTH_LE_LL</td>
<td>251</td>
<td>Bluetooth Low Energy air interface Link Layer packets, in the format described in section 2.1 PACKET FORMAT of volume 6 of the Bluetooth Specification Version 4.0 (see PDF page 2200), but without the Preamble.</td>
</tr>
<tr>
<td>LINKTYPE_WIRESHARK_UPPER_PDU</td>
<td>252</td>
<td>Reserved for Wireshark</td>
</tr>
<tr>
<td>LINKTYPE_NETLINK</td>
<td>253</td>
<td>Linux Netlink capture encapsulation</td>
</tr>
<tr>
<td>LINKTYPE_BLUETOOTH_LINUX_MONITOR</td>
<td>254</td>
<td>Bluetooth Linux</td>
</tr>
<tr>
<td>LINKTYPE_BLUETOOTH_BREDR_BB</td>
<td>255</td>
<td>Bluetooth Basic Rate and Enhanced Data Rate baseband packets</td>
</tr>
<tr>
<td>LINKTYPE_BLUETOOTH_LE_LL_WITH_PHDR</td>
<td>256</td>
<td>Bluetooth Low Energy link-layer packets</td>
</tr>
<tr>
<td>LINKTYPE_PROFIBUS_DL</td>
<td>257</td>
<td>PROFIBUS data link layer packets, as specified by IEC standard 61158-4-3, beginning with the start delimiter, ending with the end delimiter, and including all octets between them.</td>
</tr>
<tr>
<td>LINKTYPE_PKTAP</td>
<td>258</td>
<td>Apple PKTAP capture encapsulation</td>
</tr>
<tr>
<td>LINKTYPE_EPON</td>
<td>259</td>
<td>Ethernet-over-passive-optical-network packets, starting with the last 6 octets of the modified preamble as specified by 65.1.3.2 Transmit in Clause 65 of Section 5 of IEEE 802.3, followed immediately by an Ethernet frame.</td>
</tr>
<tr>
<td>LINKTYPE_IPMI_HPM_2</td>
<td>260</td>
<td>IPMI trace packets, as specified by Table 3-20 Trace Data Block Format in the PICMG HPM.2 specification The time stamps for</td>
</tr>
<tr>
<td>LINKTYPE</td>
<td>DESCRIPTION</td>
<td>NUMBER</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>--------</td>
</tr>
<tr>
<td>ZWAVE_R1_R2</td>
<td>Z-Wave RF profile R1 and R2 packets, as specified by ITU-T Recommendation G.9959, with some MAC layer fields moved.</td>
<td>261</td>
</tr>
<tr>
<td>ZWAVE_R3</td>
<td>Z-Wave RF profile R3 packets, as specified by ITU-T Recommendation G.9959, with some MAC layer fields moved.</td>
<td>262</td>
</tr>
<tr>
<td>WATTSTOPPER_DLM</td>
<td>Formats for WattStopper Digital Lighting Management (DLM) and Legrand Nitoo Open protocol common packet structure captures.</td>
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<td>Messages between ISO 14443 contactless smartcards (Proximity Integrated Circuit Card, PICC) and card readers (Proximity Coupling Device, PCD), with the message format specified by the PCAP format for ISO14443 specification</td>
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<td>Radio data system (RDS) groups, as per IEC 62106,</td>
<td>265</td>
</tr>
<tr>
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<td>266</td>
<td>USB packets, beginning with a Darwin (macOS, etc.) USB header</td>
</tr>
<tr>
<td>LINKTYPE_OPENFLOW</td>
<td>267</td>
<td>Reserved for OpenBSD DLT_OPENFLOW</td>
</tr>
<tr>
<td>LINKTYPE_SDLC</td>
<td>268</td>
<td>SDLC packets, as specified by Chapter 1, DLC Links, section Synchronous Data Link Control (SDLC) of Systems Network Architecture Formats, GA27-3136-20, without the flag fields, zero-bit insertion, or Frame Check Sequence field, containing SNA path information units (PIUs) as the payload.</td>
</tr>
<tr>
<td>LINKTYPE_TI_LLN_SNIFFER</td>
<td>269</td>
<td>Reserved for Texas Instruments protocol sniffer</td>
</tr>
<tr>
<td>LINKTYPE_LORATAP</td>
<td>270</td>
<td>LoRaTap pseudo-header, followed by the payload, which is typically the PHYPayload from the LoRaWan specification</td>
</tr>
<tr>
<td>LINKTYPE_VSOCK</td>
<td>271</td>
<td>Protocol for communication between host and guest machines in VMware and KVM hypervisors.</td>
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<tr>
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<td>Messages to and from a Nordic Semiconductor nRF Sniffer for Bluetooth LE packets, beginning with a pseudo-header</td>
</tr>
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<td>LINKTYPE_DOCSIS31_XRA31</td>
<td>273</td>
<td>DOCSIS packets and bursts, preceded by a pseudo-header giving metadata about the packet</td>
</tr>
<tr>
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<td>274</td>
<td>mPackets, as specified by IEEE 802.3br Figure 99-4, starting with the preamble and always ending with a CRC field.</td>
</tr>
<tr>
<td>LINKTYPE_DISPLAYPORT_AUX</td>
<td>275</td>
<td>DisplayPort AUX channel monitoring data as specified by VESA DisplayPort (DP) Standard preceded by a pseudo-header</td>
</tr>
<tr>
<td>LINKTYPE_LINUX_SLL2</td>
<td>276</td>
<td>Linux cooked capture encapsulation v2</td>
</tr>
<tr>
<td>LINKTYPE_SERCOS_MONITOR</td>
<td>277</td>
<td>Reserved for Sercos Monitor</td>
</tr>
<tr>
<td>LINKTYPE_OpEnVizsla</td>
<td>278</td>
<td>Openvizsla FPGA-based USB sniffer</td>
</tr>
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<td>LINKTYPE_EBHSCR</td>
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<td>Elektrobit High Speed Capture and Replay (EBHSCR) format</td>
</tr>
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<td>280</td>
<td>Records in traces from the <a href="http://fd.io">http://fd.io</a> VPP graph dispatch tracer, in the the</td>
</tr>
<tr>
<td>LINKTYPE_DSA_TAG_BRCM</td>
<td>281</td>
<td>Ethernet frames, with a switch tag inserted between the source address field and the type/length field in the Ethernet header.</td>
</tr>
<tr>
<td>LINKTYPE_DSA_TAG_BRCM_PREPEND</td>
<td>282</td>
<td>Ethernet frames, with a switch tag inserted before the destination address in the Ethernet header.</td>
</tr>
<tr>
<td>LINKTYPE_IEEE802_15_4_TAP</td>
<td>283</td>
<td>IEEE 802.15.4 Low-Rate Wireless Networks, with a pseudo-header containing TLVs with metadata preceding the 802.15.4 header.</td>
</tr>
<tr>
<td>LINKTYPE_DSA_TAG_DSA</td>
<td>284</td>
<td>Ethernet frames, with a switch tag inserted between the source address field and the type/length field in the Ethernet header.</td>
</tr>
<tr>
<td>LINKTYPE_DSA_TAG_EDSA</td>
<td>285</td>
<td>Ethernet frames, with a programmable Ethernet type switch tag inserted between the source address field and the type/length field in the Ethernet header.</td>
</tr>
<tr>
<td>LINKTYPE_ELEE</td>
<td>286</td>
<td>Payload of lawful intercept packets using the ELEE protocol. The packet begins with the ELEE protocol identifier.</td>
</tr>
</tbody>
</table>
header; it does not include any transport-layer or lower-layer headers for protocols used to transport ELEE packets.

| LINKTYPE_Z_WAVE_SERIAL | 287 | Serial frames transmitted between a host and a Z-Wave chip over an RS-232 or USB serial connection, as described in section 5 of the Z-Wave Serial API Host Application Programming Guide |
| LINKTYPE_USB_2_0 | 288 | USB 2.0, 1.1, or 1.0 packet, beginning with a PID, as described by Chapter 8 Protocol Layer of the Universal Serial Bus Specification Revision 2.0 |
| LINKTYPE_ATSC_ALP | 289 | ATSC Link-Layer Protocol frames, as described in section 5 of the A/330 Link-Layer Protocol specification, found at the ATSC 3.0 standards page, beginning with a Base Header |

### Table 1

9. Contributors

[Insert pcap developers etc. here].

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10. Acknowledgments

The authors wish to thank [insert list here] and many others for their invaluable comments.

11. References

11.1. Normative References


11.2. Informative References


Authors’ Addresses

Guy Harris (editor)

Email: gharris@sonic.net
Abstract

To improve cybersecurity posture, automation is necessary to locate what software is running on a device, whether that software has known vulnerabilities, and what, if any recommendations suppliers may have. This memo specifies a model to provide access to this information. It may optionally be discovered through manufacturer usage descriptions.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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This Internet-Draft will expire on 27 April 2022.

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1. Introduction

A number of activities have been working to improve visibility to what software is running on a system, and what vulnerabilities that software may have.

Put simply, we seek to answer two classes of questions *at scale*:

* Is this system vulnerable to a particular vulnerability?

* Which devices in a particular environment contain vulnerabilities that require some action?
Software bills of materials (SBOMs) are descriptions of what software, including versioning and dependencies, a device contains. There are different SBOM formats such as Software Package Data Exchange [SPDX] or CycloneDX[CycloneDX12].

System vulnerabilities may similarly be described using several data formats, including the aforementioned CycloneDX, Common Vulnerability Reporting Framework [CVRF], the Common Security Advisory Format [CSAF]. This information is typically used to report to customers the state of a system.

These two classes of information can be used in concert. For instance, a network management tool may discover that a system makes use of a particular software component that has a known vulnerability, and a vulnerability report may be used to indicate what if any versions of software correct that vulnerability, or whether the system exercises the vulnerable code at all.

Both classes of information elements are optional under the model specified in this memo. One can provide only an SBOM, only vulnerability information, or both an SBOM and vulnerability information.

Note that SBOM formats may also carry other information, the most common being any licensing terms. Because this specification is neutral regarding content, it is left for format developers such as the Linux Foundation, OASIS, and ISO to decide what attributes they will support.

This specification does not allow for vulnerability information to be retrieved directly from the endpoint. That’s because vulnerability information changes occur at different rates to software updates.

SBOMs and vulnerability information are advertised and retrieved through the use of a YANG augmentation of the Manufacturer User Description (MUD) model [RFC8520]. Note that the schema creates a grouping that can also be used independently of MUD. Moreover, other MUD features, such as access controls, needn’t be present.

The mechanisms specified in this document are meant to satisfy several use cases:

* A network-layer management system retrieving information from an IoT device as part of its ongoing lifecycle. Such devices may or may not have query interfaces available.
* An application-layer management system retrieving vulnerability or SBOM information in order to evaluate the posture of an application server of some form. These application servers may themselves be containers or hypervisors. Discovery of the topology of a server is beyond the scope of this memo.

To satisfy these two key use cases, objects may be found in one of three ways:

* on devices themselves
* on a web site (e.g., via URI)
* through some form of out-of-band contact with the supplier.

In the first case, devices will have interfaces that permit direct retrieval. Examples of these interfaces might be an HTTP, COAP or [OpenC2] endpoint for retrieval. There may also be private interfaces as well.

In the second case, when a device does not have an appropriate retrieval interface, but one is directly available from the manufacturer, a URI to that information must be discovered.

In the third case, a supplier may wish to make an SBOM or vulnerability information available under certain circumstances, and may need to individually evaluate requests. The result of that evaluation might be the SBOM or vulnerability itself or a restricted URL or no access.

To enable application-layer discovery, this memo defines a well-known URI [RFC8615]. Management or orchestration tools can query this well-known URI to retrieve a system's SBOM or vulnerability information. Further queries may be necessary based on the content and structure of the response.

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.

1.1. Cases Not Addressed

[ This section to be removed prior to publication ]

A separate use case may be addressed in future versions of this document:
* Related to the application layer, software as a service may involve multiple backend systems, depending on many factors. One example might be a large cloud-based service that offers spreadsheets, email, and document authoring and management. Depending on what service is being used, a different set of backend services may in turn be invoking different software that should be listed.

The reason why this use case isn't addressed here is that it may be better addressed inline within HTML. Further discussion is required.

1.2. How This Information Is Retrieved

For devices that can emit a URL or can establish a well-known URI, the mechanism may be highly automated. For devices that have a URL in either their documentation or within a QR code on a box, the mechanism is semi-automated (someone has to scan the QR code or enter the URL).

Note that vulnerability and SBOM information is likely to change at different rates. The MUD semantics provide a way for manufacturers to control how often tooling should check for those changes through the cache-validity node.

1.3. Formats

There are multiple ways to express both SBOMs and vulnerability information. When these are retrieved either directly from the device or directly from a web server, tools will need to observe the content-type header to determine precisely which format is being transmitted. Because IoT devices in particular have limited capabilities, use of a specific Accept: header in HTTP or the Accept Option in CoAP is NOT RECOMMENDED. Instead, backend tooling is encouraged to support all known formats, and SHOULD silently discard SBOM information sent with a media type that is not understood.

Some formats may support both vulnerability and software inventory information. When both vulnerability and software inventory information is available from the same location, both sbom and vuln nodes MUST indicate that. Network management systems retrieving this information MUST take note that the identical resource is being retrieved rather than retrieving it twice.

1.4. Discussion points

The following is discussion to be removed at time of RFC publication.

* Is the model structured correctly?
Are there other retrieval mechanisms that need to be specified?

Do we need to be more specific in how to authenticate and retrieve SBOMs?

What are the implications if the MUD URL is an extension in a certificate (e.g. an IDevID cert)?

2. The .well-known/transparency endpoint set

Two well known endpoints are defined:

* 

"/.well-known/sbom" retrieves an SBOM.

* 

"/.well-known/openc2" is the HTTPS binding to OpenC2.

As discussed previously, the precise format of a response is based on the Content-type provided.

3. The mud-transparency extension model extension

We now formally define this extension. This is done in two parts. First, the extension name "transparency" is listed in the "extensions" array of the MUD file. N.B., this schema extension is intended to be used wherever it might be appropriate (e.g., not just MUD).

Second, the "mud" container is augmented with a list of SBOM sources.

This is done as follows:
module: ietf-mud-transparency

augment /mud:mud:
  +--rw transparency
    +--rw (sbom-retrieval-method)?
      |  +--:(cloud)
      |  |  +--rw sboms* [version-info]
      |  |  |  +--rw version-info string
      |  |  +--rw sbom-url? inet:uri
      |  +--:(local-well-known)
      |  |  +--rw sbom-local-well-known? enumeration
      |  +--:(sbom-contact-info)
      |     +--rw sbom-contact-uri inet:uri
    +--rw (vuln-retrieval-method)?
      |  +--:(cloud)
      |  |  +--rw vuln-url? inet:uri
      |  +--:(vuln-contact-info)
      |     +--rw contact-uri inet:uri

4. The mud-sbom augmentation to the MUD YANG model

<CODE BEGINS>
file "ietf-mud-transparency@2021-10-22.yang"
module ietf-mud-transparency {
  yang-version 1.1;
  prefix mud-transparency;

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

  import ietf-mud {
    prefix mud;
    reference "RFC 8520";
  }

  organization
    "IETF OPSAWG (Ops Area) Working Group";
  contact
    "WG Web: http://tools.ietf.org/wg/opsawg/
    WG List: opsawg@ietf.org

    Editor: Eliot Lear lear@cisco.com
    Editor: Scott Rose scott.rose@nist.gov"
  description
    "This YANG module augments the ietf-mud model to provide for
    reporting of SBOMs."
revision 2021-07-06 {
    description
        "Initial proposed standard.";
    reference
        "RFC XXXX: Extension for software transparency";
}

grouping transparency-extension {
    description
        "Transparency extension grouping";
    container transparency {
        description
            "container of methods to get an SBOM.";
    choice sbom-retrieval-method {
        description
            "How to find SBOM information";
        case cloud {
            list sboms {
                key "version-info";
                description
                    "A list of SBOMs tied to different s/w or h/w versions.";
                leaf version-info {
                    type string;
                    description
                        "The version to which this SBOM refers.";
                }
            }
            leaf sbom-url {

type inet:uri;
description
"A statically located URI.";
}
}
case local-well-known {
leaf sbom-local-well-known {
    type enumeration {
        enum http {
            description
            "Use http (insecure) to retrieve SBOM information.";
        }
        enum https {
            description
            "Use https (secure) to retrieve SBOM information.";
        }
        enum coap {
            description
            "Use COAP (insecure) to retrieve SBOM";
        }
        enum coaps {
            description
            "Use COAPS (secure) to retrieve SBOM";
        }
        enum openc2 {
            description
            "Use OpenC2 endpoint. This is https://{host}/.well-known/openc2";
        }
    }
    description
    "Which communication protocol to choose.";
}
}
case sbom-contact-info {
leaf sbom-contact-uri {
    type inet:uri;
    mandatory true;
    description
    "This MUST be either a tel, http, https, or mailto uri schema that customers can use to contact someone for SBOM information.";
}
}
choice vuln-retrieval-method {


5. Examples

In this example MUD file that uses a cloud service, the modelX presents a location of the SBOM in a URL. Note, the ACLs in a MUD file are NOT required, although they are a very good idea for IP-based devices.

5.1. Without ACLS

This first MUD file demonstrates how to get SBOM and vulnerability information without ACLs.
{  
  "ietf-mud:mud": {  
    "mud-version": 1,  
    "extensions": [  
      "transparency"  
    ],  
    "ietf-mud-transparency:transparency": {  
      "sboms": [  
        {  
          "version-info": "ExOS1.1",  
          "sbom-url": "https://iot.example.com/info/modelX/sbom.json"  
        }  
      ],  
      "vuln-url": "https://iot.example.com/info/modelX/csaf.json"  
    },  
    "mud-url": "https://iot.example.com/modelX.json",  
    "mud-signature": "https://iot.example.com/modelX.p7s",  
    "last-update": "2021-07-09T05:57:58+00:00",  
    "cache-validity": 48,  
    "is-supported": true,  
    "systeminfo": "retrieving vuln and SBOM info via a cloud service",  
    "mfg-name": "Example, Inc.",  
    "documentation": "https://iot.example.com/doc/modelX",  
    "model-name": "modelX"  
  }  
}  

The second example demonstrates that just SBOM information is included.


5.2. SBOM Located on the Device

In this example, the SBOM is retrieved from the device, while vulnerability information is available from the cloud. This is likely a common case, because vendors may learn of vulnerability information more frequently than they update software.
5.3. Further contact required.

In this example, the network manager must take further steps to retrieve SBOM information. Vulnerability information is still available.
5.4. With ACLS

Finally, here is a complete example where the device provides SBOM and vulnerability information, as well as access-control information.

```json
{
    "ietf-mud:mud": {
        "mud-version": 1,
        "extensions": [
            "transparency"
        ],
        "ietf-mud-transparency:transparency": {
            "contact-info": "https://iot-device.example.com/contact-info.html",
            "vuln-url": "https://iot-device.example.com/info/modelX/csaf.json"
        },
        "mud-url": "https://iot-device.example.com/modelX.json",
        "mud-signature": "https://iot-device.example.com/modelX.p7s",
        "last-update": "2021-07-09T06:19:39+00:00",
        "cache-validity": 48,
        "is-supported": true,
        "systeminfo": "retrieving vuln and SBOM info via a cloud service",
        "mfg-name": "Example, Inc.",
        "documentation": "https://iot-device.example.com/doc/modelX",
        "model-name": "modelX"
    }
}
```
"mfg-name": "Example, Inc.",
"documentation": "https://iot.example.com/doc/modelX",
"model-name": "modelX",
"from-device-policy": {
"access-lists": {
"access-list": [
{ "name": "mud-15060-v4fr"
}
]
},
"to-device-policy": {
"access-lists": {
"access-list": [
{ "name": "mud-15060-v4to"
}
]
}
}
},
"ietf-access-control-list:acls": {
"acl": [
{
"name": "mud-15060-v4to",
"type": "ipv4-acl-type",
"aces": {
"ace": [
{ "name": "cl0-todev",
"matches": {
"ipv4": {
"ietf-acldns:src-dnsname": "cloud.example.com"
}
},
"actions": {
"forwarding": "accept"
}
}
}
]
}
},
{ "name": "mud-15060-v4fr",
"type": "ipv4-acl-type",
"aces": {
"ace": [
}
At this point, the management system can attempt to retrieve the SBOM, and determine which format is in use through the content-type header on the response to a GET request, independently repeat the process for vulnerability information, and apply ACLs, as appropriate.

6. Security Considerations

SBOMs provide an inventory of software. If firmware is available to an attacker, the attacker may well already be able to derive this very same software inventory. Manufacturers MAY restrict access to SBOM information using appropriate authorization semantics within HTTP. In particular, if a system attempts to retrieve an SBOM via HTTP and the client is not authorized, the server MUST produce an appropriate error, with instructions on how to register a particular client. One example may be to issue a certificate to the client for this purpose after a registration process has taken place. Another example would involve the use of OAUTH in combination with a federations of SBOM servers.

Another risk is a skew in the SBOM listing and the actual software inventory of a device/container. For example, a manufacturer may update the SBOM on its server, but an individual device has not been upgraded yet. This may result in an incorrect policy being applied to a device. A unique mapping of a device’s firmware version and its SBOM can minimize this risk.

To further mitigate attacks against a device, manufacturers SHOULD recommend access controls through the normal MUD mechanism.
Vulnerability information is generally made available to such databases as NIST’s National Vulnerability Database. It is possible that vendor may wish to release information early to some customers. We do not discuss here whether that is a good idea, but if it is employed, then appropriate access controls and authorization would be applied to the vulnerability resource.

7. IANA Considerations

7.1. MUD Extension

The IANA is requested to add "transparency" to the MUD extensions registry as follows:

Extension Name: transparency
Standard reference: This document

7.2. Well-Known Prefix

The following well known URIs are requested in accordance with [RFC8615]:

URI suffix: "sbom"
Change controller: "IETF"
Specification document: This memo
Related information: See ISO/IEC 19970-2 and SPDX.org

URI suffix: "openc2"
Change controller: "IETF"
Specification document: This memo
Related information: OpenC2 Project

8. References

8.1. Normative References


8.2. Informative References


Appendix A. Changes from Earlier Versions

Draft -02:
* include vulnerability information

Draft -01:
* some modest changes

Draft -00:
* Initial revision

Authors’ Addresses
Abstract

This document describes an architecture for Service Assurance for Intent-based Networking (SAIN). This architecture aims at assuring that service instances are running as expected. As services rely upon multiple sub-services provided by the underlying network devices and functions, getting the assurance of a healthy service is only possible with a holistic view of all involved elements. This architecture not only helps to correlate the service degradation with the network root cause but also the impacted services when a network component fails or degrades.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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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.

SAIN agent: A functional component that communicates with a device, a set of devices, or another agent to build an expression graph from a received assurance graph and perform the corresponding computation of the health status and symptoms.

Assurance case: According to [Piovesan2017]: "An assurance case is a structured argument, supported by evidence, intended to justify that a system is acceptably assured relative to a concern (such as safety or security) in the intended operating environment."

Assurance graph: A Directed Acyclic Graph (DAG) representing the assurance case for one or several service instances. The nodes (also known as vertices in the context of DAG) are the service instances themselves and the subservices, the edges indicate a dependency relations.

SAIN collector: A functional component that fetches or receives the computer-consumable output of the SAIN agent(s) and displays it in a user friendly form or process it locally.

DAG: Directed Acyclic Graph.

ECMP: Equal Cost Multiple Paths

Expression graph: A generic term for a DAG representing a computation in SAIN. More specific terms are:

* Subservice expressions: Is an expression graph representing all the computations to execute for a subservice.

* Service expressions: Is an expression graph representing all the computations to execute for a service instance, i.e., including the computations for all dependent subservices.

* Global computation graph: Is an expression graph representing all the computations to execute for all services instances (i.e., all computations performed).

Dependency: The directed relationship between subservice instances in the assurance graph.

Informational Dependency: Type of dependency whose health score does not impact the health score of its parent subservice or service instance(s) in the assurance graph. However, the symptoms should be taken into account in the parent service instance or subservice instance(s), for informational reasons.
Impacting Dependency: Type of dependency whose score impacts the score of its parent subservice or service instance(s) in the assurance graph. The symptoms are taken into account in the parent service instance or subservice instance(s), as the impacting reasons.

Metric: An information retrieved from the network running the assured service.

Metric engine: A functional components that maps metrics to a list of candidate metric implementations depending on the network element.

Metric implementation: Actual way of retrieving a metric from a network element.

Network service YANG module: describes the characteristics of a service as agreed upon with consumers of that service [RFC8199].

Service instance: A specific instance of a service.

Service configuration orchestrator: Quoting RFC8199, "Network Service YANG Modules describe the characteristics of a service, as agreed upon with consumers of that service. That is, a service module does not expose the detailed configuration parameters of all participating network elements and features but describes an abstract model that allows instances of the service to be decomposed into instance data according to the Network Element YANG Modules of the participating network elements. The service-to-element decomposition is a separate process; the details depend on how the network operator chooses to realize the service. For the purpose of this document, the term "orchestrator" is used to describe a system implementing such a process."

SAIN orchestrator: A functional component that is in charge of fetching the configuration specific to each service instance and converting it into an assurance graph.

Health status: Score and symptoms indicating whether a service instance or a subservice is "healthy". A non-maximal score must always be explained by one or more symptoms.

Health score: Integer ranging from 0 to 100 indicating the health of a subservice. A score of 0 means that the subservice is broken, a score of 100 means that the subservice in question is operating as expected.

Subservice: Part or functionality of the network system that can be independently assured as a single entity in assurance graph.
Strongly connected component: subset of a directed graph such that there is a (directed) path from any node of the subset to any other node. A DAG does not contain any strongly connected component.

Symptom: Reason explaining why a service instance or a subservice is not completely healthy.

2. Introduction

Network Service YANG Modules [RFC8199] describe the configuration, state data, operations, and notifications of abstract representations of services implemented on one or multiple network elements.

Quoting RFC8199: "Network Service YANG Modules describe the characteristics of a service, as agreed upon with consumers of that service. That is, a service module does not expose the detailed configuration parameters of all participating network elements and features but describes an abstract model that allows instances of the service to be decomposed into instance data according to the Network Element YANG Modules of the participating network elements. The service-to-element decomposition is a separate process; the details depend on how the network operator chooses to realize the service. For the purpose of this document, the term "orchestrator" is used to describe a system implementing such a process."

Service configuration orchestrators deploy Network Service YANG Modules [RFC8199] that will infer network-wide configuration and, therefore the configuration of the appropriate device modules (Section 3 of [RFC8969]). Network configuration is based on these device YANG modules, with protocol/encoding such as NETCONF/XML [RFC6241], RESTCONF/JSON [RFC8040], gNMI/gRPC/protobuf, etc. Knowing that a configuration is applied doesn’t imply that the service is running as expected (e.g., the service might be degraded because of a failure in the network), the network operator must monitor the service operational data at the same time as the configuration (Section 3.3 of [RFC8969]). The industry has been standardizing on telemetry to push network element performance information.

A network administrator needs to monitor her network and services as a whole, independently of the use cases or the management protocols. With different protocols come different data models, and different ways to model the same type of information. When network administrators deal with multiple protocols, the network management must perform the difficult and time-consuming job of mapping data models: the model used for configuration with the model used for monitoring. This problem is compounded by a large, disparate set of data sources (MIB modules, YANG models [RFC7950], IPFIX information...
elements [RFC7011], syslog plain text [RFC3164], TACACS+ [RFC8907], RADIUS [RFC2865], etc.). In order to avoid this data model mapping, the industry converged on model-driven telemetry to stream the service operational data, reusing the YANG models used for configuration. Model-driven telemetry greatly facilitates the notion of closed-loop automation whereby events/status from the network drive remediation changes back into the network.

However, it proves difficult for network operators to correlate the service degradation with the network root cause. For example, why does my L3VPN fail to connect? Why is this specific service slow? The reverse, i.e., which services are impacted when a network component fails or degrades, is even more interesting for the operators. For example, which services are impacted when this specific optic dBM begins to degrade? Which applications are impacted by this ECMP imbalance? Is that issue actually impacting any other customers?

Intent-based approaches are often declarative, starting from a statement of "The service works as expected" and trying to enforce it. Such approaches are mainly suited for greenfield deployments.

Aligned with Section 3.3 of [RFC7149], and instead of approaching intent from a declarative way, this architecture focuses on already defined services and tries to infer the meaning of "The service works as expected". To do so, the architecture works from an assurance graph, deduced from the service definition and from the network configuration. In some cases, the assurance graph may also be explicitly completed to add an intent not exposed in the service model itself (e.g. the service must rely on a backup physical path). This assurance graph is decomposed into components, which are then assured independently. The root of the assurance graph represents the service to assure, and its children represent components identified as its direct dependencies; each component can have dependencies as well. The SAIN architecture updates the assurance graph when services are modified or when the network conditions change.
When a service is degraded, the SAIN architecture will highlight, to the best of its knowledge, where in the assurance service graph to look, as opposed to going hop by hop to troubleshoot the issue. Not only can this architecture help to correlate service degradation with network root cause/symptoms, but it can deduce from the assurance graph the number and type of services impacted by a component degradation/failure. This added value informs the operational team where to focus its attention for maximum return. Indeed, the operational team should focus his priority on the degrading/failing components impacting the highest number customers, especially the ones with the SLA contracts involving penalties in case of failure.

This architecture provides the building blocks to assure both physical and virtual entities and is flexible with respect to services and subservices, of (distributed) graphs, and of components (Section 3.8).

3. Architecture

The goal of SAIN is to assure that service instances are operating correctly and if not, to pinpoint what is wrong. More precisely, SAIN computes a score for each service instance and outputs symptoms explaining that score, especially why the score is not maximal. The score augmented with the symptoms is called the health status.

The SAIN architecture is a generic architecture, applicable to multiple environments. Obviously wireline but also wireless, but also different domains such as 5G, NFV domain with a virtual infrastructure manager (VIM), etc. And as already noted, for physical or virtual devices, as well as virtual functions. Thanks to the distributed graph design principle, graphs from different environments/orchestrator can be combined together.

As an example of a service, let us consider a point-to-point L2VPN connection (i.e., pseudowire). Such a service would take as parameters the two ends of the connection (device, interface or subinterface, and address of the other end) and configure both devices (and maybe more) so that a L2VPN connection is established between the two devices. Examples of symptoms might be "Interface has high error rate" or "Interface flapping", or "Device almost out of memory".

To compute the health status of such a service, the service definition is decomposed into an assurance graph formed by subservices linked through dependencies. Each subservice is then turned into an expression graph that details how to fetch metrics from the devices and compute the health status of the subservice. The subservice expressions are combined according to the dependencies between the subservices in order to obtain the expression graph which computes the health status of the service.

The overall SAIN architecture is presented in Figure 1. Based on the service configuration, the SAIN orchestrator decomposes the assurance graph, to the best of its knowledge. It then sends to the SAIN agents the assurance graph along some other configuration options. The SAIN agents are responsible for building the expression graph and computing the health statuses in a distributed manner. The collector is in charge of collecting and displaying the current inferred health status of the service instances and subservices. Finally, the automation loop is closed by having the SAIN collector providing feedback to the network/service orchestrator.

In order to make agents, orchestrators and collectors from different vendors interoperable, their interface is defined as a YANG model in a companion RFC [I-D.ietf-opsawg-service-assurance-yang]. In Figure 1, the communications that are normalized by this model are tagged with a "Y". The use of these YANG modules is further explained in Section 3.6.
In order to produce the score assigned to a service instance, the architecture performs the following tasks:

* Analyze the configuration pushed to the network device(s) for configuring the service instance and decide: which information is needed from the device(s), such a piece of information being called a metric, which operations to apply to the metrics for computing the health status.
* Stream (via telemetry [RFC8641]) operational and config metric values when possible, else continuously poll.

* Continuously compute the health status of the service instances, based on the metric values.

3.1. Inferring a Service Instance Configuration into an Assurance Graph

In order to structure the assurance of a service instance, the service instance is decomposed into so-called subservice instances. Each subservice instance focuses on a specific feature or subpart of the service.

The decomposition into subservices is an important function of this architecture, for the following reasons.

* The result of this decomposition provides a relational picture of a service instance, that can be represented as a graph (called assurance graph) to the operator.

* Subservices provide a scope for particular expertise and thereby enable contribution from external experts. For instance, the subservice dealing with the optics health should be reviewed and extended by an expert in optical interfaces.

* Subservices that are common to several service instances are reused for reducing the amount of computation needed.

The assurance graph of a service instance is a DAG representing the structure of the assurance case for the service instance. The nodes of this graph are service instances or subservice instances. Each edge of this graph indicates a dependency between the two nodes at its extremities: the service or subservice at the source of the edge depends on the service or subservice at the destination of the edge.

Figure 2 depicts a simplistic example of the assurance graph for a tunnel service. The node at the top is the service instance, the nodes below are its dependencies. In the example, the tunnel service instance depends on the "peer1" and "peer2" tunnel interfaces, which in turn depend on the respective physical interfaces, which finally depend on the respective "peer1" and "peer2" devices. The tunnel service instance also depends on the IP connectivity that depends on the IS-IS routing protocol.
Depicting the assurance graph helps the operator to understand (and assert) the decomposition. The assurance graph shall be maintained during normal operation with addition, modification and removal of service instances. A change in the network configuration or topology shall be reflected in the assurance graph. As a first example, a change of routing protocol from IS-IS to OSPF would change the assurance graph accordingly. As a second example, assuming that ECMP is in place for the source router for that specific tunnel; in that case, multiple interfaces must now be monitored, on top of the monitoring the ECMP health itself.
3.1.1. Circular Dependencies

The edges of the assurance graph represent dependencies. An assurance graph is a DAG if and only if there are no circular dependencies among the subservices, and every assurance graph should avoid circular dependencies. However, in some cases, circular dependencies might appear in the assurance graph.

First, the assurance graph of a whole system is obtained by combining the assurance graph of every service running on that system. Here combining means that two subservices having the same type and the same parameters are in fact the same subservice and thus a single node in the graph. For instance, the subservice of type "device" with the only parameter (the device id) set to "PE1" will appear only once in the whole assurance graph even if several services rely on that device. Now, if two engineers design assurance graphs for two different services, and engineer A decides that an interface depends on the link it is connected to, but engineer B decides that the link depends on the interface it is connected to, then when combining the two assurance graphs, we will have a circular dependency interface -> link -> interface.

Another case possibly resulting in circular dependencies is when subservices are not properly identified. Assume that we want to assure a kubernetes cluster. If we represent the cluster by a subservice and the network service by another subservice, we will likely model that the network service depends on the cluster, because the network service is orchestrated by kubernetes, and that the cluster depends on the network service because it implements the communications. A finer decomposition might distinguish between the resources for executing containers (a part of our cluster subservice) and the communication between the containers (which could be modelled in the same way as communication between routers).

In any case, it is likely that circular dependencies will show up in the assurance graph. A first step would be to detect circular dependencies as soon as possible in the SAIN architecture. Such a detection could be carried out by the SAIN Orchestrator. Whenever a circular dependency is detected, the newly added service would not be monitored until more careful modelling or alignment between the different teams (engineer A and B) remove the circular dependency.

As more elaborate solution we could consider a graph transformation:

* Decompose the graph into strongly connected components.

* For each strongly connected component:
- Remove all edges between nodes of the strongly connected component
- Add a new "top" node for the strongly connected component
- For each edge pointing to a node in the strongly connected component, change the destination to the "top" node
- Add a dependency from the top node to every node in the strongly connected component.

Such an algorithm would include all symptoms detected by any subservice in one of the strongly component and make it available to any subservice that depends on it. Figure 3 shows an example of such a transformation. On the left-hand side, the nodes c, d, e and f form a strongly connected component. The status of a should depend on the status of c, d, e, f, g, and h, but this is hard to compute because of the circular dependency. On the right hand-side, a depends on all this nodes as well, but there the circular dependency has been removed.

![Graph transformation figure](image)

Figure 3: Graph transformation
3.2. Intent and Assurance Graph

The SAIN orchestrator analyzes the configuration of a service instance to:

* Try to capture the intent of the service instance, i.e., what is the service instance trying to achieve.
* Decompose the service instance into subservices representing the network features on which the service instance relies.

The SAIN orchestrator must be able to analyze configuration from various devices and produce the assurance graph.

To schematize what a SAIN orchestrator does, assume that the configuration for a service instance touches two devices and configure on each device a virtual tunnel interface. Then:

* Capturing the intent would start by detecting that the service instance is actually a tunnel between the two devices, and stating that this tunnel must be functional. This is the current state of SAIN, however it does not completely capture the intent which might additionally include, for instance, the latency and bandwidth requirements of this tunnel.
* Decomposing the service instance into subservices would result in the assurance graph depicted in Figure 2, for instance.

In order for SAIN to be applied, the configuration necessary for each service instance should be identifiable and thus should come from a "service-aware" source. While the Figure 1 makes a distinction between the SAIN orchestrator and a different component providing the service instance configuration, in practice those two components are mostly likely combined. The internals of the orchestrator are currently out of scope of this document.

3.3. Subservices

A subservice corresponds to subpart or a feature of the network system that is needed for a service instance to function properly. In the context of SAIN, subservice is actually a shortcut for subservice assurance, that is the method for assuring that a subservice behaves correctly.
Subservices, just as with services, have high-level parameters that specify the type and specific instance to be assured. For example, assuring a device requires the specific deviceID as parameter. For example, assuring an interface requires the specific combination of deviceID and interfaceID.

A subservice is also characterized by a list of metrics to fetch and a list of computations to apply to these metrics in order to infer a health status.

3.4. Building the Expression Graph from the Assurance Graph

From the assurance graph is derived a so-called global computation graph. First, each subservice instance is transformed into a set of subservice expressions that take metrics and constants as input (i.e., sources of the DAG) and produce the status of the subservice, based on some heuristics. Then for each service instance, the service expressions are constructed by combining the subservice expressions of its dependencies. The way service expressions are combined depends on the dependency types (impacting or informational). Finally, the global computation graph is built by combining the service expressions. In other words, the global computation graph encodes all the operations needed to produce health statuses from the collected metrics.

Subservices shall be device independent. To justify this, let’s consider the interface operational status. Depending on the device capabilities, this status can be collected by an industry-accepted YANG module (IETF, Openconfig), by a vendor-specific YANG module, or even by a MIB module. If the subservice was dependent on the mechanism to collect the operational status, then we would need multiple subservice definitions in order to support all different mechanisms. This also implies that, while waiting for all the metrics to be available via standard YANG modules, SAIN agents might have to retrieve metric values via non-standard YANG models, via MIB modules, Command Line Interface (CLI), etc., effectively implementing a normalization layer between data models and information models.

In order to keep subservices independent from metric collection method, or, expressed differently, to support multiple combinations of platforms, OSes, and even vendors, the architecture introduces the concept of "metric engine". The metric engine maps each device-independent metric used in the subservices to a list of device-specific metric implementations that precisely define how to fetch values for that metric. The mapping is parameterized by the characteristics (model, OS version, etc.) of the device from which the metrics are fetched.
3.5. Building the Expression from a Subservice

Additionally, to the list of metrics, each subservice defines a list of expressions to apply on the metrics in order to compute the health status of the subservice. The definition or the standardization of those expressions (also known as heuristic) is currently out of scope of this standardization.

3.6. Open Interfaces with YANG Modules

The interfaces between the architecture components are open thanks to the YANG modules specified in YANG Modules for Service Assurance [I-D.ietf-opsawg-service-assurance-yang]; they specify objects for assuring network services based on their decomposition into so-called subservices, according to the SAIN architecture.

This module is intended for the following use cases:

* Assurance graph configuration:
  - Subservices: configure a set of subservices to assure, by specifying their types and parameters.
  - Dependencies: configure the dependencies between the subservices, along with their types.

* Assurance telemetry: export the health status of the subservices, along with the observed symptoms.

Some examples of YANG instances can be found in Appendix A of [I-D.ietf-opsawg-service-assurance-yang].

3.7. Handling Maintenance Windows

Whenever network components are under maintenance, the operator want to inhibit the emission of symptoms from those components. A typical use case is device maintenance, during which the device is not supposed to be operational. As such, symptoms related to the device health should be ignored, as well as symptoms related to the device-specific subservices, such as the interfaces, as their state changes is probably the consequence of the maintenance.

To configure network components as "under maintenance" in the SAIN architecture, the ietf-service-assurance model proposed in [I-D.ietf-opsawg-service-assurance-yang] specifies an "under-maintenance" flag per service or subservice instance. When this flag is set and only when this flag is set, the companion field "maintenance-contact" must be set to a string that identifies the
person or process who requested the maintenance. When a service or subservice is flagged as under maintenance, it may report a generic "Under Maintenance" symptom, for propagation towards subservices that depend on this specific subservice: any other symptom from this service, or by one of its impacting dependencies MUST NOT be reported.

We illustrate this mechanism on three independent examples based on the assurance graph depicted in Figure 2:

* Device maintenance, for instance upgrading the device OS. The operator sets the "under-maintenance" flag for the subservice "Peer1" device. This inhibits the emission of symptoms from "Peer1 Physical Interface", "Peer1 Tunnel Interface" and "Tunnel Service Instance". All other subservices are unaffected.

* Interface maintenance, for instance replacing a broken optic. The operator sets the "under-maintenance" flag for the subservice "Peer1 Physical Interface". This inhibits the emission of symptoms from "Peer 1 Tunnel Interface" and "Tunnel Service Instance". All other subservices are unaffected.

* Routing protocol maintenance, for instance modifying parameters or redistribution. The operator sets the "under-maintenance" flag for the subservice "IS-IS Routing Protocol". This inhibits the emission of symptoms from "IP connectivity" and "Tunnel Service Instance". All other subservices are unaffected.

3.8. Flexible Architecture

The SAIN architecture is flexible in terms of components. While the SAIN architecture in Figure 1 makes a distinction between two components, the SAIN configuration orchestrator and the SAIN orchestrator, in practice those two components are mostly likely combined. Similarly, the SAIN agents are displayed in Figure 1 as being separate components. Practically, the SAIN agents could be either independent components or directly integrated in monitored entities. A practical example is an agent in a router.

The SAIN architecture is also flexible in terms of services and subservices. Most examples in this document deal with the notion of Network Service YANG modules, with well-known service such as L2VPN or tunnels. However, the concepts of services is general enough to cross into different domains. One of them is the domain of service management on network elements, with also requires its own assurance. Examples includes a DHCP server on a Linux server, a data plane, an IPFIX export, etc. The notion of "service" is generic in this architecture. Indeed, a configured service can itself be a
subservice for someone else. Exactly like a DHCP server/ data plane/ IPFIX export can be considered as subservices for a device, exactly like an routing instance can be considered as a subservice for a L3VPN, exactly like a tunnel can considered as a subservice for an application in the cloud. Exactly like a service function can be be considered as a subservice for a service function chain [RFC7665]. The assurance graph is created to be flexible and open, regardless of the subservice types, locations, or domains.

The SAIN architecture is also flexible in terms of distributed graphs. As shown in Figure 1, our architecture comprises several agents. Each agent is responsible for handling a subgraph of the assurance graph. The collector is responsible for fetching the subgraphs from the different agents and gluing them together. As an example, in the graph from Figure 2, the subservices relative to Peer 1 might be handled by a different agent than the subservices relative to Peer 2 and the Connectivity and IS-IS subservices might be handled by yet another agent. The agents will export their partial graph and the collector will stitch them together as dependencies of the service instance.

And finally, the SAIN architecture is flexible in terms of what it monitors. Most, if not all examples, in this document refer to physical components but this is not a constrain. Indeed, the assurance of virtual components would follow the same principles and an assurance graph composed of virtualized components (or a mix of virtualized and physical ones) is well possible within this architecture.

3.9. Timing

The SAIN architecture requires time synchronization, with Network Time Protocol (NTP) [RFC5905] as a candidate, between all elements: monitored entities, SAIN agents, Service Configuration Orchestrator, the SAIN collector, as well as the SAIN Orchestrator. This guarantees the correlations of all symptoms in the system, correlated with the right assurance graph version.

The SAIN agent might have to remove some symptoms for specific subservice symptoms, because there are outdated and not relevant any longer, or simply because the SAIN agent needs to free up some space. Regardless of the reason, it’s important for a SAIN collector (re-)connecting to a SAIN agent to understand the effect of this garbage collection. Therefore, the SAIN agent contains a YANG object specifying the date and time at which the symptoms history starts for the subservice instances.
3.10. New Assurance Graph Generation

The assurance graph will change along the time, because services and subservices come and go (changing the dependencies between subservices), or simply because a subservice is now under maintenance. Therefore an assurance graph version must be maintained, along with the date and time of its last generation. The date and time of a particular subservice instance (again dependencies or under maintenance) might be kept. From a client point of view, an assurance graph change is triggered by the value of the assurance-graph-version and assurance-graph-last-change YANG leaves. At that point in time, the client (collector) follows the following process:

* Keep the previous assurance-graph-last-change value (let’s call it time T)
* Run through all subservice instance and process the subservice instances for which the last-change is newer that the time T
* Keep the new assurance-graph-last-change as the new referenced date and time

4. Security Considerations

The SAIN architecture helps operators to reduce the mean time to detect and mean time to repair. As such, it should not cause any security threats. However, the SAIN agents must be secure: a compromised SAIN agents could be sending wrong root causes or symptoms to the management systems.

Except for the configuration of telemetry, the agents do not need "write access" to the devices they monitor. This configuration is applied with a YANG module, whose protection is covered by Secure Shell (SSH) [RFC6242] for NETCONF or TLS [RFC8446] for RESTCONF.

The data collected by SAIN could potentially be compromising to the network or provide more insight into how the network is designed. Considering the data that SAIN requires (including CLI access in some cases), one should weigh data access concerns with the impact that reduced visibility will have on being able to rapidly identify root causes.

If a closed loop system relies on this architecture then the well known issue of those system also applies, i.e., a lying device or compromised agent could trigger partial reconfiguration of the service or network. The SAIN architecture neither augments or reduces this risk.
5. IANA Considerations

This document includes no request to IANA.

6. Contributors

* Youssef El Fathi
* Eric Vyncke

7. Open Issues


8. References

8.1. Normative References


8.2. Informative References


[I-D.irtf-nmrg-ibn-intent-classification]

[Piovesan2017]


Appendix A. Changes between revisions

v00 - v01

* Cover the feedback received during the WG call for adoption
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Authors’ Addresses

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

Jean Quilbeuf
Huawei
Email: jean.quilbeuf@huawei.com

Diego R. Lopez
Telefonica I+D
Don Ramon de la Cruz, 82
Madrid 28006
Spain
Email: diego.r.lopez@telefonica.com

Dan Voyer
Bell Canada
Canada
Email: daniel.voyer@bell.ca

Thangam Arumugam
Cisco Systems, Inc.
Milpitas (California),
United States of America
Email: tarumuga@cisco.com
YANG Modules for Service Assurance
draft-ietf-opsawg-service-assurance-yang-01

Abstract

This document proposes YANG modules for the Service Assurance for Intent-based Networking Architecture.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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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 terms used in this document are defined in [I-D.ietf-opsawg-service-assurance-architecture]

2. Introduction

The "Service Assurance for Intent-based Networking Architecture" draft-ietf-opsawg-service-assurance-architecture, specifies the architecture and all of its components for service assurance. This document complements the architecture by providing open interfaces between components. More specifically, the goal is to provide YANG modules for the purpose of service assurance in a format that is:

- machine readable
- vendor independent
- augmentable

3. YANG Models Overview

The main YANG module, ietf-service-assurance, defines objects for assuring network services based on their decomposition into so-called subservices. The subservices are hierarchically organised by dependencies. The subservices, along with the dependencies, constitute an assurance graph. This module should be supported by an agent, able to interact with the devices in order to produce a health status and symptoms for each subservice in the assurance graph. This module is intended for the following use cases:

- Assurance graph configuration:
* Subservices: configure a set of subservices to assure, by specifying their types and parameters.

* Dependencies: configure the dependencies between the subservices, along with their type.

  o Assurance telemetry: export the health status of the subservices, along with the observed symptoms.

The second YANG module, ietf-service-assurance-device, extends the ietf-service-assurance module to add support for the subservice DeviceHealthy. Additional subservice types might be added the same way.

The third YANG module, ietf-service-assurance-device, is another example that extends the ietf-service-assurance-device module. This extension adds support for the subservice InterfaceHealthy.

The fourth YANG module, example-service-assurance-device-acme, extends the ietf-service-assurance-device module as an example to add support for the subservice DeviceHealthy, with specifics for the fictional ACME Corporation. Additional vendor-specific parameters might be added the same way.

Finally, the modules ietf-service-assurance-ip-connectivity and ietf-service-assurance-is-is are provided to completely model the example from the SAIN architecture draft [I-D.ietf-opsawg-service-assurance-architecture].

4. Base ietf-service-assurance YANG module

4.1. Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance data model.
module: ietf-service-assurance
   +--ro assurance-graph-version      yang:counter32
   +--ro assurance-graph-last-change yang:date-and-time
   +--rw subservices
      +--rw subservice* [type id]
         +--rw type                            identityref
         +--rw id                              string
         +--ro last-change?                    yang:date-and-time
         +--ro label?                         string
         +--rw under-maintenance?            boolean
         +--rw maintenance-contact           string
         +--rw (parameter)?
            +--:(service-instance-parameter)
               +--rw service-instance-parameter
                  +--rw service          string
                  +--rw instance-name    string
         +--ro health-score?                  uint8
         +--ro symptoms-history-start?        yang:date-and-time
         +--rw symptoms
            +--ro symptom* [start-date-time id]
               +--ro id                   string
               +--ro health-score-weight? uint8
               +--ro description?        string
               +--ro start-date-time     yang:date-and-time
               +--ro stop-date-time?     yang:date-and-time
         +--rw dependencies
            +--rw dependency* [type id]
               +--rw type                -> /subservices/subservice/type
               +--rw id                  -> /subservices/subservice[type=current()]/..[/type]/id
               +--rw dependency-type?    identityref

4.2. Concepts

The ietf-service-assurance YANG model assumes an identified number of subservices, to be assured independently. A subservice is a feature or a subpart of the network system that a given service instance might depend on. Example of subservices include:

- DeviceHealthy: whether a device is healthy, and if not, what are the symptoms. Potential symptoms are "CPU overloaded", "Out of RAM", or "Out of TCAM".

- ConnectivityHealthy: given two IP addresses owned by two devices, what is the quality of the connection between them. Potential symptoms are "No route available" or "ECMP Imbalance".
The first example is a subservice representing a subpart of the network system, while the second is a subservice representing a feature of the network. In both cases, these subservices might depend on other subservices, for instance, the connectivity might depend on a subservice representing the routing mechanism and on a subservice representing ECMP.

The status of each subservice contains a list of symptoms. Each symptom is specified by a unique id and contains a health-score-weight (the impact to the health score incurred by this symptom), a label (text describing what the symptom is), and dates and times at which the symptom was detected and stopped being detected. While the unique id is sufficient as an unique key list, the start-date-time second key help sorting and retrieving relevant symptoms.

The assurance of a given service instance can be obtained by composing the assurance of the subservices that it depends on, via the dependency relations.

A subservice declaration MUST provide:

- A type: identity inheriting of the base identity for subservice,
- An id: string uniquely identifying the subservice among those with the same identity,
- One or more parameters, which should be specified in an augmenting model, as described in the next sections.

The type and id uniquely identify a given subservice. They are used to indicate the dependencies. Dependencies have types as well. Two types are specified in the model:

- Impacting: such a dependency indicates an impact on the health of the dependent,
- Informational: such a dependency might explain why the dependent has issues but does not impact its health.

To illustrate the difference between "impacting" and "informational", consider the subservice InterfaceHealthy, representing a network interface. If the device to which the network interface belongs goes down, the network interface will transition to a down state as well. Therefore, the dependency of InterfaceHealthy towards DeviceHealthy is "impacting". On the other hand, as a the dependency towards the ECMPLoad subservice, which checks that the load between ECMP remains stable throughout time, is only "informational". Indeed, services might be perfectly healthy even if the load distribution...
between ECMP changed. However, such an instability might be a relevant symptom for diagnosing the root cause of a problem.

Service instances MUST be modeled as a particular type of subservice with two parameters, a type and an instance name. The type is the name of the service defined in the network orchestrator, for instance "point-to-point-l2vpn". The instance name is the name assigned to the particular instance that we are assuring, for instance the name of the customer using that instance.

The "under-maintenance" and "maintenance-contact" flags inhibit the emission of symptoms for that subservice and subservices that depend on them. See Section 3.7 of [I-D.ietf-opsawg-service-assurance-architecture] for a more detailed discussion.

By specifying service instances and their dependencies in terms of subservices, one defines the whole assurance to apply for them. An assurance agent supporting this model should then produce telemetry in return with, for each subservice: a health-status indicating how healthy the subservice is and when the subservice is not healthy, a list of symptoms explaining why the subservice is not healthy.

4.3. YANG Module

```<CODE BEGINS> file "ietf-service-assurance@2021-06-28.yang"

module ietf-service-assurance {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-service-assurance";
  prefix service-assurance;

  import ietf-yang-types {
    prefix yang;
  }

  organization "IETF NETCONF (Network Configuration) Working Group";
  contact "WG Web: <https://datatracker.ietf.org/wg/netconf/>
           WG List: <mailto:netconf@ietf.org>
           Author: Benoit Claise <mailto:benoit.claise@huawei.com>
           Author: Jean Quilbeuf <mailto:jean.quilbeu@huawei.com>;"
  description "This module defines objects for assuring network services based on their decomposition into so-called subservices, according to the SAIN (Service Assurance for Intent-based Networking) architecture.

The subservices hierarchically organised by dependencies constitute an assurance graph. This module should be supported by an assurance agent, able to interact with the devices in order to produce a health status and symptoms for each subservice in the assurance graph.

This module is intended for the following use cases:
* Assurance graph configuration:
  * subservices: configure a set of subservices to assure, by specifying their types and parameters.
  * dependencies: configure the dependencies between the subservices, along with their type.
* Assurance telemetry: export the health status of the subservices, along with the observed symptoms.


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This version of this YANG module is part of RFC XXXX; see the RFC itself for full legal notices.

TO DO:
- Better type (IETF or OC) for device-id, interface-id, etc.
- Have a YANG module for IETF and one for OC?";

revision 2021-06-28 {
  description
    "Made service-instance parameters mandatory.";
  reference
    "RFC xxxx: Title to be completed";
}
revision 2020-01-13 {
  description
    "Added the maintenance window concept.";
  reference
    "RFC xxxx: Title to be completed";
revision 2019-11-16 {
    description
        "Initial revision.";
    reference
        "RFC xxxx: Title to be completed";
}

identity subservice-idty {
    description
        "Root identity for all subservice types.";
}

identity service-instance-idty {
    base subservice-idty;
    description
        "Identity representing a service instance.";
}

identity dependency-type {
    description
        "Base identity for representing dependency types.";
}

identity informational-dependency {
    base dependency-type;
    description
        "Indicates that symptoms of the dependency might be of interest for the dependent, but the status of the dependency should not have any impact on the dependent.";
}

identity impacting-dependency {
    base dependency-type;
    description
        "Indicates that the status of the dependency directly impacts the status of the dependent.";
}

grouping symptom {
    description
        "Contains the list of symptoms for a specific subservice.";
    leaf id {
        type string;
        description
            "A unique identifier for the symptom.";
    }
    leaf health-score-weight {

type uint8 {
  range "0 .. 100";
}

description
  "The weight to the health score incurred by this symptom. The higher the
  value, the more of an impact this symptom has. If a subservice health
  score is not 100, there must be at least one symptom with a health
  score weight larger than 0.";

leaf description {
  type string;
  description
    "Description of the symptom, i.e. text describing what the symptom is, to
    be computer-consumable and be displayed on a human interface. ";
}

leaf start-date-time {
  type yang:date-and-time;
  description
    "Date and time at which the symptom was detected.";
}

leaf stop-date-time {
  type yang:date-and-time;
  description
    "Date and time at which the symptom stopped being detected.";
}

}

grouping subservice-dependency {
  description
    "Represent a dependency to another subservice.";
  leaf type {
    type leafref {
      path "/subservices/subservice/type";
    }
    description
      "The type of the subservice to refer to (e.g. DeviceHealthy).";
  }
  leaf id {
    type leafref {
      path "/subservices/subservice[type=current()]/../type]/id";
    }
    description
      "The identifier of the subservice to refer to.";
  }
  leaf dependency-type {
    type identityref {
      base dependency-type;
    }
  }
}
leaf assurance-graph-version {
    type yang:counter32;
    mandatory true;
    config false;
    description
    "The assurance graph version, which increases by 1 for each new version, after
    the changes (dependencies and/or maintenance windows parameters) are applied
    to the subservice(s).";
}

leaf assurance-graph-last-change {
    type yang:date-and-time;
    mandatory true;
    config false;
    description
    "Date and time at which the assurance graph last changed after the changes
    (dependencies and/or maintenance windows parameters) are applied to the
    subservice(s). These date and time must be more recent or equal compared to
    the more recent value of any changed subservices last-change";
}

container subservices {
    description
    "Root container for the subservices.";
    list subservice {
        key "type id";
        description
        "List of subservice configured.";
        leaf type {
            type identityref {
                base subservice-idty;
            }
            description
            "Name of the subservice, e.g. DeviceHealthy.";
        }
        leaf id {
            type string;
            description
            "Unique identifier of the subservice instance, for each type.";
        }
        leaf last-change {
            type yang:date-and-time;
            config false;
            description
            "Date and time at which the assurance graph for this subservice"
instance last changed, i.e. dependencies and/or maintenance windows parameters.

leaf label {
  type string;
  config false;
  description "Label of the subservice, i.e. text describing what the subservice is to be displayed on a human interface."
}

leaf under-maintenance {
  type boolean;
  default "false";
  description "An optional flag indicating whether this particular subservice is under maintenance. Under this circumstance, the subservice symptoms and the symptoms of its dependencies in the assurance graph should not be taken into account. Instead, the subservice should send a 'Under Maintenance' single symptom.

The operator changing the under-maintenance value must set the maintenance-contact variable.

When the subservice is not under maintenance any longer, the under-maintenance flag must return to its default value and the under-maintenance-owner variable deleted."
}

leaf maintenance-contact {
  when "../under-maintenance = 'true'";
  type string;
  mandatory true;
  description "A string used to model an administratively assigned name of the resource that changed the under-maintenance value to 'true.

It is suggested that this name contain one or more of the following: IP address, management station name, network manager’s name, location, or phone number. In some cases the agent itself will be the owner of an entry. In these cases, this string shall be set to a string starting with 'monitor'.";
}

choice parameter {
  description "Specify the required parameters per subservice type."
  container service-instance-parameter {
    when "derived-from-or-self(../type, 'service-assurance:service-instance-idty')"
    description "Specify the parameters of a service instance."
    leaf service {
leaf instance-name {
  type string;
  mandatory true;
  description
    "Name of the instance for that service.";
}

leaf health-score {
  type uint8 {
    range "0 .. 100";
  }
  config false;
  description
    "Score value of the subservice health. A value of 100 means that subservice is healthy. A value of 0 means that the subservice is broken. A value between 0 and 100 means that the subservice is degraded.";
}

leaf symptoms-history-start {
  type yang:date-and-time;
  config false;
  description
    "Date and time at which the symptoms history starts for this subservice instance, either because the subservice instance started at that date and time or because the symptoms before that were removed due to a garbage collection process.";
}

container symptoms {
  description
    "Symptoms for the subservice.";
  list symptom {
    key "start-date-time id";
    config false;
    description
      "List of symptoms the subservice. While the start-date-time key is not necessary per se, this would get the entries sorted by start-date-time for easy consumption.";
    uses symptom;
  }
}

container dependencies {

5. Subservice Extension: ietf-service-assurance-device YANG module

5.1. Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance-device data model.

module: ietf-service-assurance-device

    augment /service-assurance:subservices/service-assurance:subservice/service-assurance:parameter:
        +--rw parameters
            +--rw device    string

5.2. Complete Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance and ietf-service-assurance-device data models.
5.3. Concepts

As the number of subservices will grow over time, the YANG module is designed to be extensible. A new subservice type requires the precise specifications of its type and expected parameters. Let us illustrate the example of the new DeviceHealthy subservice type. As the name implies, it monitors and reports the device health, along with some symptoms in case of degradation.

For our DeviceHealthy subservice definition, the new identity device-idty is specified, as an inheritance from the base identity for subservices. This indicates to the assurance agent that we are now assuring the health of a device.
The typical parameter for the configuration of the DeviceHealthy subservice is the name of the device that we want to assure. By augmenting the parameter choice from ietf-service-assurance YANG module for the case of the device-idty subservice type, this new parameter is specified.

5.4. YANG Module

<CODE BEGINS> file "ietf-service-assurance-device@2021-06-28.yang"

module ietf-service-assurance-device {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-service-assurance-device";
  prefix service-assurance-device;

  import ietf-service-assurance {
    prefix service-assurance;
  }

  organization
    "IETF NETCONF (Network Configuration) Working Group";
  contact
    "WG Web: <https://datatracker.ietf.org/wg/netconf/>
    WG List: <mailto:netconf@ietf.org>
    Author: Benoit Claise <mailto:benoit.claise@huawei.com>
    Author: Jean Quilbeuf <mailto:jean.quilbeuf@huawei.com>";
  description
    "This module extends the ietf-service-assurance module to add support for the subservice DeviceHealthy."

  Checks whether a network device is healthy.

  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 (RFC 2119) (RFC 8174) when, and only when, they appear in all capitals, as shown here.

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revision 2021-06-28 {
    description "Renamed the container for parameters.";
    reference "RFC xxxx: Title to be completed";
}
revision 2020-01-13 {
    description "Added the maintenance window concept.";
    reference "RFC xxxx: Title to be completed";
}
revision 2019-11-16 {
    description "Initial revision.";
    reference "RFC xxxx: Title to be completed";
}

identity device-idty {
    base service-assurance:subservice-idty;
    description "Network Device is healthy.";
}

augment "/service-assurance:subservices/service-assurance:subservice/service-assurance:parameter" {
    description "Specify the required parameters for a new subservice type";
    container parameters {
        when "derived-from-or-self(../service-assurance:type, 'device-idty')";
        description "Specify the required parameters for the device-idty subservice type";
        leaf device {
            type string;
            mandatory true;
            description "The device to monitor.";
        }
    }
}

6.1. Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance-interface data model.

module: ietf-service-assurance-interface

augment /service-assurance:subservices/service-assurance:subservice/service-assurance:parameter:
++--rw device       string
++--rw interface    string

6.2. Complete Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance, ietf-service-assurance-device, and ietf-service-assurance-interface data models.
module: ietf-service-assurance
  +--ro assurance-graph-version yang:counter32
  +--ro assurance-graph-last-change yang:date-and-time
  +--rw subservices
    +--rw subservice* [type id]
      +--rw type identityref
      +--rw id string
      +--ro last-change? yang:date-and-time
      +--ro label? string
      +--ro under-maintenance? boolean
      +--rw maintenance-contact string
      +--rw (parameter)?
        +--:(service-instance-parameter)
          +--rw service-instance-parameter
            +--rw service string
            +--rw instance-name string
        +--:(service-assurance-interface:parameters)
          +--rw service-assurance-interface:parameters
            +--rw service-assurance-interface:device string
            +--rw service-assurance-interface:interface string
        +--:(service-assurance-device:parameters)
          +--rw service-assurance-device:parameters
            +--rw service-assurance-device:device string
      +--ro health-score? uint8
      +--ro symptoms-history-start? yang:date-and-time
      +--rw symptoms
        +--ro symptom* [start-date-time id]
          +--ro id string
          +--ro health-score-weight? uint8
          +--ro description? string
          +--ro start-date-time yang:date-and-time
          +--ro stop-date-time? yang:date-and-time
      +--rw dependencies
        +--rw dependency* [type id]
          +--rw type -> /subservices/subservice/type
          +--rw id -> /subservices/subservice[type=current()]/
            ../type]/id
          +--rw dependency-type? identityref

6.3. Concepts

For our InterfaceHealthy subservice definition, the new interface-
idity is specified, as an inheritance from the base identity for
subservices. This indicates to the assurance agent that we are now
assuring the health of an interface.

The typical parameters for the configuration of the InterfaceHealthy
subservice are the name of the device and, on that specific device, a
specific interface. By augmenting the parameter choice from ietf-
service-assurance YANG module for the case of the interface-idty
subservice type, those two new parameter are specified.

6.4.  YANG Module

<CODE BEGINS> file "ietf-service-assurance-interface@2021-06-28.yang"

module ietf-service-assurance-interface {
  yang-version 1.1;
  prefix service-assurance-interface;

  import ietf-service-assurance {
    prefix service-assurance;
  }

  organization
    "IETF OPSAWG Working Group";

  contact
    "WG Web:  <https://datatracker.ietf.org/wg/opsawg/>"
    "WG List:  <mailto:opsawg@ietf.org>"
    "Author:   Benoit Claise  <mailto:benoit.claise@huawei.com>"
    "Author:   Jean Quilbeuf  <mailto:jean.quilbeuf@huawei.com>";

  description
    "This module extends the ietf-service-assurance module to add
    support for the subservice InterfaceHealthy."

  Checks whether an interface is healthy.

  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 (RFC 2119)
  (RFC 8174) when, and only when, they appear in all
  capitals, as shown here.

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  RFC itself for full legal notices. ";


revision 2021-06-28 {
    description
        "Regroup parameters in a container.";
    reference
        "RFC xxxx: Title to be completed";
}
revision 2020-01-13 {
    description
        "Initial revision.";
    reference
        "RFC xxxx: Title to be completed";
}

identity interface-idty {
    base service-assurance:subservice-idty;
    description
        "Checks whether an interface is healthy.";
}

augment "/service-assurance:subservices/service-assurance:subservice/service-assurance:parameter" {
    description
        "Specify the required parameters for the interface-idty subservice type";
    container parameters {
        when "derived-from-or-self(../service-assurance:type, 'interface-idty')";
        description
            "Required parameters for the interface-idty subservice type";
        leaf device {
            type string;
            mandatory true;
            description
                "Device supporting the interface.";
        }
        leaf interface {
            type string;
            mandatory true;
            description
                "Name of the interface.";
        }
    }
}

<CODE ENDS>
7. Vendor-specific Subservice Extension: example-service-assurance-device-acme YANG module

7.1. Tree View

The following tree diagram [RFC8340] provides an overview of the example-service-assurance-device-acme data model.

module: example-service-assurance-device-acme

augment /service-assurance:subservices/service-assurance:subservice/service-assurance:parameter:
  +--rw parameters
  |    +--rw device  string
  |    +--rw acme-specific-parameter  string

7.2. Complete Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance, ietf-service-assurance-device, and example-service-assurance-device-acme data models.
module: ietf-service-assurance
  +--ro assurance-graph-version yang:counter32
  +--ro assurance-graph-last-change yang:date-and-time
  +--rw subservices
     +--rw subservice* [type id]
        +--rw type identityr
        +--rw id string
        +--ro last-change? yang:date-and-time
        +--ro label? string
        +--rw under-maintenance? boolean
        +--rw maintenance-contact string
        +--rw (parameter)?
           +--:(service-instance-parameter)
              +--rw service-instance-parameter
                 +--rw service string
                 +--rw instance-name string
           +--:(service-assurance-device:parameters)
              +--rw service-assurance-device:parameters
                 +--rw service-assurance-device:device string
           +--:(example-service-assurance-device-acme:parameters)
              +--rw example-service-assurance-device-acme:parameters
                 +--rw example-service-assurance-device-acme:device string
                 +--rw example-service-assurance-device-acme:acme-specific-parameter string
           +--:(service-assurance-interface:parameters)
              +--rw service-assurance-interface:parameters
                 +--rw service-assurance-interface:device string
                 +--rw service-assurance-interface:interface string
           +--ro health-score? uint8
           +--ro symptoms-history-start? yang:date-and-time
           +--rw symptoms
              +--ro symptom* [start-date-time id]
                 +--ro id string
                 +--ro health-score-weight? uint8
                 +--ro description? string
                 +--ro start-date-time yang:date-and-time
                 +--ro stop-date-time? yang:date-and-time
           +--rw dependencies
              +--rw dependency* [type id]
                 +--rw type -> /subservices/subservice/type
                 +--rw id -> /subservices/subservice[type=current()]/..[/type]/id
                 +--rw dependency-type? identityref

7.3. Concepts

Under some circumstances, vendor-specific subservice types might be required. As an example of this vendor-specific implementation, this section shows how to augment the ietf-service-assurance-device module
to add support for the subservice DeviceHealthy, specific to the ACME Corporation. The new parameter is acme-specific-parameter.

7.4. YANG Module

module example-service-assurance-device-acme {
  yang-version 1.1;
  namespace "urn:example:example-service-assurance-device-acme";
  prefix example-service-assurance-device-acme;

  import ietf-service-assurance {
    prefix service-assurance;
  }
  import ietf-service-assurance-device {
    prefix service-assurance-device;
  }

  organization
    "IETF NETCONF (Network Configuration) Working Group";
  contact
    "WG Web: <https://datatracker.ietf.org/wg/netconf/>
     WG List: <mailto:netconf@ietf.org>
     Author: Benoit Claise <mailto:benoit.claise@huawei.com>
     Author: Jean Quilbeuf <mailto:jean.quilbeuf@huawei.com>";
  description
    "This module extends the ietf-service-assurance-device module to add support for the subservice DeviceHealthy, specific to the ACME Corporation.

    ACME Network Device is healthy.

    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 (RFC 2119) (RFC 8174) when, and only when, they appear in all capitals, as shown here.

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    This version of this YANG module is part of RFC XXXX; see the
RFC itself for full legal notices. ";

revision 2021-06-28 {
  description
    "Renamed the parameters container.";
  reference
    "RFC xxxx: Title to be completed";
}
revision 2020-01-13 {
  description
    "Added the maintenance window concept.";
  reference
    "RFC xxxx: Title to be completed";
}
revision 2019-11-16 {
  description
    "Initial revision.";
  reference
    "RFC xxxx: Title to be completed";
}

identity device-acme-idty {
  base service-assurance-device:device-idty;
  description
    "Network Device is healthy.";
}

augment "/service-assurance:subservices/service-assurance:subservice/service-assurance:parameter" {
  description
    "Specify the required parameters for a new subservice type";
  container parameters {
    when "derived-from-or-self(../service-assurance:type, 'device-acme-idty')";
    description
      "Specify the required parameters for the device-acme-idty subservice type";
    leaf device {
      type string;
      mandatory true;
      description
        "The device to monitor.";
    }
    leaf acme-specific-parameter {
      type string;
      mandatory true;
      description
        "The ACME Corporation sepcific parameter.";
    }
  }
}
8. Further Extensions: IP Connectivity and IS-IS subservices

8.1. IP Connectivity Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance-ip-connectivity data model.

module: ietf-service-assurance-ip-connectivity

augment /service-assurance:subservices/service-assurance:subservice/service-assurance:parameter:
  +--rw parameters
    +--rw device1     string
    +--rw address1    inet:ip-address
    +--rw device2     string
    +--rw address2    inet:ip-address

To specify the connectivity that we are interested in, we specify two IP addresses and two devices. The subservice assures that the connectivity between IP address 1 on device 1 and IP address 2 on device 2 is healthy.

8.2. IS-IS Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance-is-is data model.

module: ietf-service-assurance-is-is

augment /service-assurance:subservices/service-assurance:subservice/service-assurance:parameter:
  +--rw parameters
    +--rw instance-name    string

The parameter of this subservice is the name of the IS-IS instance to assure.

8.3. Global Tree View

The following tree diagram [RFC8340] provides an overview of the ietf-service-assurance, ietf-service-assurance-device, example-service-assurance-device-acme, ietf-service-assurance-ip-connectivity and ietf-service-assurance-is-is data models.

module: ietf-service-assurance
---ro assurance-graph-version        yang:counter32
---ro assurance-graph-last-change    yang:date-and-time
---rw subservices
  +--rw subservice* [type id]
  |  +--rw type                                                      identityr
ef
  |  +--rw id
  |  +--ro last-change?                                             string
  +--and-time
  |  +--ro label?                                                    string
  |  +--rw under-maintenance?                                        boolean
  |  +--rw maintenance-contact                                       string
  |  +--rw (parameter)??
  |     +--:(service-instance-parameter)
  |     |  +--rw service-instance-parameter
  |     |     +--rw service          string
  |     |     +--rw instance-name    string
  |     +--:(service-assurance-ip-connectivity:parameters)
  |     |  +--rw service-assurance-ip-connectivity:device1     string
  |     |     +--rw service-assurance-ip-connectivity:address1    inet:ip-addr
  |     +--:(service-assurance-is-is:parameters)
  |     |  +--rw service-assurance-is-is:instance-name    string
  |     +--:(service-assurance-device:parameters)
  |     |  +--rw service-assurance-device:device    string
  |     +--:(example-service-assurance-device-acme:parameters)
  |     |  +--rw example-service-assurance-device-acme:device
  |     |     +--rw example-service-assurance-device-acme:acme-specific-parameter    string
  +--:(service-assurance-interface:parameters)
  |  +--rw service-assurance-interface:device       string
  |  +--rw service-assurance-interface:interface    string
  +--ro health-score?                                             uint8
  +--ro symptoms-history-start?                                   yang:date-and-time
  +--rw symptoms
  |  +--ro symptom* [start-date-time id]
  |     +--ro id                                       string
  |     +--ro health-score-weight?                     uint8
  |     +--ro description?                            string
  |     +--ro start-date-time                        yang:date-and-time
  |     +--ro stop-date-time                         yang:date-and-time
  +--rw dependencies
  |  +--rw dependency* [type id]
  |     +--rw type                              -> /subservices/subservice[type=current()]/
  |     |  +--rw id                                       -> /subservices/subservice[type=current()]/..
  |     |     +--rw id
8.4. IP Connectivity YANG Module

<CODE BEGINS> file "ietf-service-assurance-ip-connectivity@2021-06-28.yang"

module ietf-service-assurance-ip-connectivity {
  yang-version 1.1;
  prefix service-assurance-ip-connectivity;

  import ietf-inet-types {
    prefix inet;
  }
  import ietf-service-assurance {
    prefix service-assurance;
  }

  organization
    "IETF OPSAWG Working Group";
  contact
    "WG Web: <https://datatracker.ietf.org/wg/opsawg/>
    WG List: <mailto:opsawg@ietf.org>
    Author: Benoit Claise <mailto:benoit.claise@huawei.com>
    Author: Jean Quilbeuf <mailto:jean.quilbeuf@huawei.com>";
  description
    "This module extends the ietf-service-assurance module to add support for the subservice ip-connectivity.

    Checks whether the ip connectivity between two ip addresses belonging to two network devices is healthy.

    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 (RFC 2119) (RFC 8174) when, and only when, they appear in all capitals, as shown here.

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identity ip-connectivity-idty {
    base service-assurance:subservice-idty;
    description
        "Checks connectivity between two IP addresses.";
}

augment "/service-assurance:subservices/service-assurance:subservice/service-assurance:parameter" {
    description
        "Specify the required parameters for the ip-connectivity-idty subservice type";
    container parameters {
        when "derived-from-or-self(../service-assurance:type, 'ip-connectivity-idty')";
        description
            "Required parameters for the ip-connectivity-idty subservice type";
    leaf device1 {
        type string;
        mandatory true;
        description
            "Device at the first end of the connection.";
    }
    leaf address1 {
        type inet:ip-address;
        mandatory true;
        description
            "Address at the first end of the connection.";
    }
    leaf device2 {
        type string;
        mandatory true;
        description
            "Device at the second end of the connection.";
    }
    leaf address2 {
        type inet:ip-address;
        mandatory true;
        description
            "Address at the second end of the connection.";
    }
}
8.5. IS-IS YANG Module

```yang
module ietf-service-assurance-is-is {  
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-service-assurance-is-is";
  prefix service-assurance-is-is;

  import ietf-service-assurance {  
    prefix service-assurance;
  }

  organization  
    "IETF NETCONF (Network Configuration) Working Group";
  contact  
    "WG Web:  <https://datatracker.ietf.org/wg/netconf/>  
    WG List:  <mailto:netconf@ietf.org>  
    Author:  Benoit Claise  <mailto:benoit.claise@huawei.com>  
    Author:  Jean Quilbeuf  <mailto:jean.quilbeuf@huawei.com>";
  description  
    "This module extends the ietf-service-assurance module to add  
    support for the subservice IS-ISHealthy.  

    Checks whether an IS-IS instance is healthy.

    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 (RFC 2119)  
    (RFC 8174) when, and only when, they appear in all  
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}
```
9. Guidelines for Specific Subservice Extension

The base YANG module defined in Section 4.3 only defines a single type of subservices that represent service instances. As explained above, this model is meant to be augmented so that a variety of subservices can be used in the assurance graph. In this section, we propose some guidelines in order to build these extensions.

First, the specific subservice must be given an adequate unique short name that will be used to form longer names (e.g. module name, prefix
...) appearing in the YANG module. The short name identifies the type of subpart of feature that the subservice will represent, for instance if the subservice will assure the health of a network interface then "interface" is an adequate short name. If the subservice will assure the IS-IS routing protocol, then "is-is" is an adequate short name. The short name must be in kebab-case.

In this section, by subservice YANG module, we mean "YANG module that extends ietf-service-assurance in order to define a specific subservice".

9.1. Module Name

For subservice YANG modules vetted by the IETF, the module name should be "ietf-service-assurance-" followed by the short name. For instance, "ietf-service-assurance-interface" or "ietf-service-assurance-is-is".

For subservice YANG module that are directly provided by vendors, we propose that they use the company in the prefix. For example, the prefix for the company "acme" would be "acme-assurance-" and the YANG modules would be "acme-assurance-interface", "acme-assurance-is-is", etc.

9.2. Module Namespace

For subservice YANG modules vetted by the IETF, the module namespace should be "urn:ietf:params:xml:ns:yang:ietf-service-assurance-" followed by the short name. For instance, "urn:ietf:params:xml:ns:yang:ietf-service-assurance-interface" or "urn:ietf:params:xml:ns:yang:ietf-service-assurance-is-is".

For subservice YANG module that are directly provided by vendors, a similar pattern can be used with the prefix being a namespace controlled by the vendor.

9.3. Module Prefix

For subservice YANG modules vetted by the IETF, the module prefix should be "service-assurance-" followed by the short name. For instance, "service-assurance-interface" or "service-assurance-is-is".

For subservice YANG module that are directly provided by vendors, the same pattern can be used provided it does not conflict with an imported prefix.
9.4. Subservice Specific Identity

Each augment specific to a subservice must define an identity representing the type of subpart or features of the network system that are assured by the subservice. As required in the "ietf-service-assurance" module (see Section 4.3), that identity must be based on the "subservice-idty" identity.

For subservice YANG modules vetted by the IETF, the subservice specific identity should be the short name of the subservice followed by "/idty". For instance, "interface-idty" or "is-is-identity".

For subservice YANG module that are directly provided by vendors, the same pattern can be used.

9.5. Parameters

For subservice YANG modules vetted by the IETF, the parameters specific to the subservice should be placed in a container named "parameters". That container must be used to augment the "parameter" choice from the module "ietf-service-assurance" (see Section 4.3 and that augment must be guarded so that it is effective only for subservice instance whose type is the subservice specific identity from Section 9.4.

For subservice YANG module that are directly provided by vendors, the same pattern can be used.

10. 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. These are the subtrees and data nodes and their sensitivity/vulnerability:

- /subservices/subservice/type
- /subservices/subservice/id
- /subservices/subservice/under-maintenance
- /subservices/subservice/maintenance-contact

11. IANA Considerations

11.1. The IETF XML Registry

This document registers two URIs in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registrations are requested:

  Registrant Contact: The NETCONF WG of the IETF.
  XML: N/A, the requested URI is an XML namespace.

  Registrant Contact: The NETCONF WG of the IETF.
  XML: N/A, the requested URI is an XML namespace.

  Registrant Contact: The NETCONF WG of the IETF.
  XML: N/A, the requested URI is an XML namespace.

11.2. The YANG Module Names Registry

This document registers three YANG modules in the YANG Module Names registry [RFC7950]. Following the format in [RFC7950], the following registrations are requested:
name:       ietf-service-assurance
prefix:     inc
reference:  RFC XXXX

name:       ietf-service-assurance-device
prefix:     inc
reference:  RFC XXXX

name:       ietf-service-assurance-interface
prefix:     inc
reference:  RFC XXXX

12. Open Issues
-None

13. References

13.1. Normative References

[I-D.ietf-opsawg-service-assurance-architecture]
Claise, B., Quilbeuf, J., Lopez, D., Voyer, D., and T. Arumugam, "draft-claise-opsawg-service-assurance-
architecture", 2020.

and A. Bierman, Ed., "Network Configuration Protocol
(NETCONF)", RFC 6241, DOI 10.17487/RFC6241, June 2011,

[RFC6242]  Wasserman, M., "Using the NETCONF Protocol over Secure
Shell (SSH)", RFC 6242, DOI 10.17487/RFC6242, June 2011,

RFC 7950, DOI 10.17487/RFC7950, August 2016,

Protocol", RFC 8040, DOI 10.17487/RFC8040, January 2017,
13.2. Informative References


13.3. URIs


Appendix A. Example of YANG instances

This section contains examples of YANG instances that conform to the YANG modules. The validity of these data instances has been checked using yangson [1]. Yangson requires a YANG library [RFC7895] to define the complete model against which the data instance must be validated. We provide in Appendix B the JSON library file, named "ietf-service-assurance-library.json", that we used for validation.

We provide below the contents of the file "example_configuration_instance.json" which contains the configuration data that models the Figure 2 of
The instance can be validated with yangson by using the invocation "yangson -v example_configuration_instance.json ietf-service-assurance-library.json", assuming all the files (YANG and JSON) defined in this draft reside in the current folder.

<CODE BEGINS> file "example_configuration_instance.json"

```json
{
  "ietf-service-assurance:subservices": {
    "subservice": [
      {
        "type": "service-instance-idty",
        "id": "simple-tunnel/example",
        "service-instance-parameter": {
          "service": "simple-tunnel",
          "instance-name": "example"
        },
        "dependencies": {
          "dependency": [
            {
              "type": "ietf-service-assurance-interface:interface-idty",
              "id": "interface/peer1/tunnel0",
              "dependency-type": "impacting-dependency"
            },
            {
              "type": "ietf-service-assurance-interface:interface-idty",
              "id": "interface/peer2/tunnel9",
              "dependency-type": "impacting-dependency"
            },
            {
              "type": "ietf-service-assurance-ip-connectivity:ip-connectivity-idty",
              "id": "connectivity/peer1/2001:db8::1/peer2/2001:db8::2",
              "ietf-service-assurance-ip-connectivity:parameters": {
                "device1": "Peer1",
                "address1": "2001:db8::1",
                "device2": "Peer2",
                "address2": "2001:db8::2"
              },
              "dependencies": {
```
"dependency": [
  {
    "type": "ietf-service-assurance-interface:interface-idty",
    "id": "interface/peer1/physical0",
    "dependency-type": "impacting-dependency"
  },
  {
    "type": "ietf-service-assurance-interface:interface-idty",
    "id": "interface/peer2/physical5",
    "dependency-type": "impacting-dependency"
  },
  {
    "type": "ietf-service-assurance-is-is:is-is-idty",
    "id": "is-is/instance1",
    "dependency-type": "impacting-dependency"
  }
],
"type": "ietf-service-assurance-is-is:is-is-idty",
"id": "is-is/instance1",
"ietf-service-assurance-is-is:parameters": {
  "instance-name": "instance1"
},
{
  "type": "ietf-service-assurance-interface:interface-idty",
  "id": "interface/peer1/tunnel0",
  "ietf-service-assurance-interface:parameters": {
    "device": "Peer1",
    "interface": "tunnel0"
  }
},
"dependencies": {
  "dependency": [
    {
      "type": "ietf-service-assurance-interface:interface-idty",
      "id": "interface/peer1/physical0",
      "dependency-type": "impacting-dependency"
    }
  ]
},
{
  "type": "ietf-service-assurance-interface:interface-idty",
  "id": "interface/peer1/physical0",
  "ietf-service-assurance-interface:parameters": {
    "device": "Peer1",
    "interface": "physical0"
  }
}
"interface": "physical0",
},
"dependencies": {
  "dependency": [
    {
      "type": "ietf-service-assurance-device:device-idty",
      "id": "interface/peer1",
      "dependency-type": "impacting-dependency"
    }
  ]
},
"type": "ietf-service-assurance-device:device-idty",
"id": "interface/peer1",
"ietf-service-assurance-device:parameters": {
  "device": "Peer1"
},
"type": "ietf-service-assurance-interface:interface-idty",
"id": "interface/peer2/tunnel9",
"ietf-service-assurance-interface:parameters": {
  "device": "Peer2",
  "interface": "tunnel9"
},
"dependencies": {
  "dependency": [
    {
      "type": "ietf-service-assurance-interface:interface-idty",
      "id": "interface/peer2/physical5",
      "dependency-type": "impacting-dependency"
    }
  ]
},
"type": "ietf-service-assurance-interface:interface-idty",
"id": "interface/peer2/physical5",
"ietf-service-assurance-interface:parameters": {
  "device": "Peer2",
  "interface": "physical5"
},
"dependencies": {
  "dependency": [
    {
      "type": "ietf-service-assurance-device:device-idty",
      "id": "interface/peer2",
      "dependency-type": "impacting-dependency"
    }
  ]
}
"dependency-type": "impacting-dependency"
  }
}
"
},
{ "type": "ietf-service-assurance-device:device-idty",
  "id": "interface/peer2",
  "ietf-service-assurance-device:parameters": {
    "device": "Peer2"
  }
}]
}
]

<CODE ENDS>

Appendix B. YANG Library for Service Assurance

This section provides the JSON encoding of the YANG library [RFC7895] listing all modules defined in this draft and their dependencies. This library can be used to validate data instances using yangson, as explained in the previous section.

<CODE BEGINS> file "ietf-service-assurance-library.json"

{
  "ietf-yang-library:modules-state": {
    "module-set-id": "ietf-service-assurance@2020-01-13",
    "module": [
      { "name": "ietf-service-assurance",
        "revision": "2021-06-28",
        "conformance-type": "implement"
      },
      { "name": "ietf-service-assurance-device",
        "revision": "2021-06-28",
        "conformance-type": "implement"
      },
      { "name": "ietf-service-assurance-interface",
        "revision": "2021-06-28",
        "conformance-type": "implement"
      }
    ]
  }
}

<CODE ENDS>
Appendix C. Changes between revisions

v00 - v01

- Added needed subservice to model example from architecture draft
- Added guideline section for naming models
- Added data instance examples and validation procedure
Added the "parameters" container in the interface YANG module to correct a bug.

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Authors’ Addresses

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

Jean Quilbeuf
Huawei
Email: jean.quilbeuf@huawei.com

Paolo Lucente
NTT
Siriusdreef 70-72
Hoofddorp, WT 2132
Netherlands
Email: paolo@ntt.net

Paolo Fasano
TIM S.p.A
via G. Reiss Romoli, 274
10148 Torino
Italy
Email: paolo2.fasano@telecomitalia.it

Thangam Arumugam
Cisco Systems, Inc.
Milpitas (California)
United States
Email: tarumuga@cisco.com
A YANG Model for Network and VPN Service Performance Monitoring

draft-ietf-opsawg-yang-vpn-service-pm-01

Abstract

The data model defined in RFC 8345 introduces vertical layering relationships between networks that can be augmented to cover network and service topologies. This document defines a YANG module for both network performance monitoring (PM) and VPN service performance monitoring that can be used to monitor and manage network performance on the topology at higher layer or the service topology between VPN sites.

The YANG model defined in this document is designed as an augmentation to the network topology YANG model defined in RFC 8345 and draws on relevant YANG types defined in RFC 6991, RFC 8345, and RFC 8532.

Status of This Memo

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Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."
1. Introduction

[RFC8969] describes a framework for automating service and network management with YANG models, proposing the performance measurement telemetry model to be tied with the service, such as Layer 3 VPN and
Layer 2 VPN, or network models to monitor the overall network performance or Service Level Agreements (SLA).

This document defines a YANG module [RFC7950] for both network performance monitoring and VPN service performance monitoring. This module can be used to monitor and manage network performance on the topology level or the service topology between VPN sites, in particular.

This document does not introduce new metrics for network performance or mechanisms for measuring network performance, but uses the existing mechanisms and statistics to show the performance monitoring statistics at the network and service layers. The YANG module defined in this document is designed as an augmentation to the network topology YANG model defined in [RFC8345].

This document uses the common VPN YANG module defined in [I-D.ietf-opsawg-vpn-common].

Appendix A provides a set of examples to illustrate the use of the module.

2. 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.

Tree diagrams used in this document follow the notation defined in [RFC8340].

3. Network and VPN Service Performance Monitoring Model Usage

Models are key for automating network management operations. According to [RFC8969], together with service and network models, performance measurement telemetry models are needed to monitor network performance to meet specific service requirements (typically captured in an SLA). The YANG module defined in this document is designed to derive VPN or network level performance data based on lower-level data collected via monitoring counters of the involved devices.
As shown in Figure 1, in the context of layering model architecture described in [RFC8309], the network and VPN service performance monitoring (PM) model can be used to expose some performance information to the above layer. Such an information can be used by an orchestrator to subscribe to performance data. The network controller will then notify the orchestrator about corresponding parameter changes.

Before using the network and VPN service PM model, the mapping between the VPN service topology and the underlying physical network should be setup. Also, the performance monitoring data per link in the underlying network can be collected using network performance measurement method such as MPLS Loss and Delay Measurement [RFC6374].

The performance monitoring information reflecting the quality of the network or VPN service (e.g., end to end network performance data between source node and destination node in the network or between VPN sites) can be computed and aggregated, for example, the information from Traffic Engineering Database (TED), defined in [RFC7471], [RFC8570], or [RFC8571] or LMAP [RFC8194].

The measurement and report intervals that are associated with these performance data usually depend on the configuration parameters.
3.1. Collecting Data via Pub/Sub Mechanism

Some applications such as service-assurance applications, which must maintain a continuous view of operational data and state, can use the subscription model [RFC8641] to subscribe to the specific network performance data or VPN service performance data they are interested in, at the data source.

The data source can, then, use the network and VPN service assurance model defined in this document and the YANG Push model [RFC8641] to distribute specific telemetry data to target recipients.

3.2. Collecting Data via Retrieval Methods

To obtain a snapshot of a large amount of performance data from a network element (including network controllers), service-assurance applications may use methods such as retrieving performance data or RPC commands defined as part of YANG models.

4. Description of The Data Model

This document defines the YANG module, "ietf-network-vpn-pm", which is an augmentation to the "ietf-network" and "ietf-network-topology".

The performance monitoring data augments the service topology as shown in Figure 2.

```
+----------------------          +-----------------------+
| ietf-network          |          | Network and VPN Service|
| ietf-network-topology |<--------| Performance Monitoring |
|                        |         | Model                  |
|------------------------|---------+------------------------+

Figure 2: Module Augmentation
```

4.1. Layering Relationship between Multiple Layers of Topology

[RFC8345] defines a YANG data model for network/service topologies and inventories. The service topology described in [RFC8345] includes the virtual topology for a service layer above Layer 1 (L1), Layer 2 (L2), and Layer 3 (L3). This service topology has the generic topology elements of node, link, and terminating point. One typical example of a service topology is described in Figure 3 of [RFC8345]: two VPN service topologies instantiated over a common L3 topology. Each VPN service topology is mapped onto a subset of nodes from the common L3 topology.
Figure 3 illustrates an example of a topology that maps between the VPN service topology and an underlying network:

VPN 1
+-----------------------+    +---------------------+
/S1C-[VN3]...       /    /S2A
/             /    /-[VN1]-----[VN3]- /
/       /    /    /    /    /  :  :  /
/      /  S1A  :  :  :  :   :  :  :
/S1B-[VN2]-----[VN1]- /    /    /
+-----------------------+    +---------------------+

Site-1A : +---------:--: ----:---:---+ Site-1C
[CE1]___:/  [N1]___________[N2]___/[CE3]
:     :        /    /      /    /
[CE5]__:[__/:/  /  /  /__/ [N5]
:  :  :  :  :  :  :
Site-2A /:  /   /__ [N4]________ [N3]---[CE4]
/  :  :  :  :  :  :
/Site-1B /:  /  /   /________/  : Site-2B
[CE2]---[N4]___________ [N3]---/----[CE4]
+-----------------------+

Legend: N:node  VN:VPN-Node

Figure 3: Example of Topology Mapping Between VPN Service Topology and Underlying Network

As shown in Figure 3, two VPN services topologies are both built on top of one common underlying physical network:

VPN 1: This service topology supports hub-spoke communications for 'customer 1' connecting the customer’s access at three sites: ‘Site-1A’, ‘Site-1B’, and ‘Site-1C’. These sites are connected to nodes that are mapped to node 1 (N1), node 2 (N2), and node 4 (N4) in the underlying physical network. ‘Site-1A’ plays the role of hub while ‘Site-1B’ and ‘Site-1C’ are configured as spoke.

VPN 2: This service supports any-to-any communications for 'customer 2' connecting the customer’s access at two sites: ‘Site-2A’ and ‘Site-2B’. These sites are connected to nodes that are mapped to nodes 1 (N1) and node 3 (N3) in the underlying physical network. ‘Site-2A’ and ‘Site-2B’ have ‘any-to-any’ role.
4.2. Network Level

For network performance monitoring, the container of "networks" in [RFC8345] do not need to be extended.

For VPN service performance monitoring, the container "service-type" is defined to indicate the VPN type, e.g., L3VPN or Virtual Private LAN Service (VPLS). The values are taken from [I-D.ietf-opsawg-vpn-common]. When a network topology instance contains the L3VPN or other L2VPN network type, it represents a VPN instance that can perform performance monitoring.

This model defines the following set of network level attributes:

"vpn-id": Refers to an identifier of VPN service defined in [I-D.ietf-opsawg-vpn-common]). This identifier is used to correlate the performance status with the network service configuration.

"vpn-service-topology": Indicates the type of VPN topology. This model supports "any-to-any", "Hub and Spoke" (where Hubs can exchange traffic), and "Hub and Spoke disjoint" (where Hubs cannot exchange traffic) that are taken from [I-D.ietf-opsawg-vpn-common]. These VPN topology types can be used to describe how VPN sites communicate with each other.

module: ietf-network-vpn-pm
augment /nw:networks/nw:network/nw:network-types:
  +--rw service-type!
  +--rw service-type? identityref
augment /nw:networks/nw:network:
  +--rw vpn-pm-attributes
    +--rw vpn-id?           vpn-common:vpn-id
    +--rw vpn-service-topology? identityref

Figure 4: Network Level View of the Hierarchies

4.3. Node Level

For network performance monitoring, a container of "pm-attributes" is augmented to the list of "node" that are defined in [RFC8345]. And the leaf of "node-type" indicates the device type of Provider Edge (PE), Provider (P) device, or Autonomous System Border Router (ASBR), so that the performance metric between any two nodes each with specific node type can be reported.

For VPN service performance monitoring, this model defines only the following minimal set of node level network topology attributes:
"role": Defines the role in a particular VPN service topology. The roles are taken from [I-D.ietf-opsawg-vpn-common] (e.g., any-to-any-role, spoke-role, hub-role).

"vpn-summary-statistics": Lists a set of IPv4 statistics, IPv6 statistics, and MAC statistics. These statistics are specified separately.

```
augment /nw:networks/nw:network/nw:node:
    +--rw pm-attributes
    |    +--rw node-type? identityref
    |    +--rw role? identityref
    |    +--ro vpn-summary-statistics
    |    |    +--ro ipv4
    |    |    |    +--ro maximum-routes? uint32
    |    |    |    +--ro total-active-routes? uint32
    |    |    +--ro ipv6
    |    |    |    +--ro maximum-routes? uint32
    |    |    |    +--ro total-active-routes? uint32
    |    |    +--ro mac-num
    |    |    |    +--ro mac-num-limit? uint32
    |    |    +--ro total-active-mac-num? uint32
```

Figure 5: Node Level View of the Hierarchies

4.4. Link and Termination Point Level

The ‘links’ are classified into two types: topology link defined in [RFC8345] and abstract link of a VPN between PEs.

The performance data of a link is a collection of counters that report the performance status.
augment /nw:networks/nw:network/nt:link:
  +--rw pm-attributes
    +--rw low-percentile? percentile
    +--rw middle-percentile? percentile
    +--rw high-percentile? percentile
    +--ro pm-source? string
    +--ro reference-time? yang:date-and-time
    +--ro measurement-interval? uint32
  +--ro pm-statistics
    +--ro loss-statistics
      +--ro packet-loss-count? yang:counter64
      +--ro packet-reorder-count? yang:counter64
      +--ro packets-out-of-seq-count? yang:counter64
      +--ro packets-dup-count? yang:counter64
      +--ro loss-ratio? percentage
    +--ro delay-statistics
      +--ro direction? identityref
      +--ro unit-value? identityref
      +--ro min-delay-value? yang:gauge64
      +--ro max-delay-value? yang:gauge64
      +--ro low-delay-percentile? yang:gauge64
      +--ro middle-delay-percentile? yang:gauge64
      +--ro high-delay-percentile? yang:gauge64
    +--ro jitter-statistics
      +--ro unit-value? identityref
      +--ro min-jitter-value? yang:gauge32
      +--ro max-jitter-value? yang:gauge32
      +--ro low-jitter-percentile? yang:gauge32
      +--ro middle-jitter-percentile? yang:gauge32
      +--ro high-jitter-percentile? yang:gauge32
    +--ro protocol-type? identityref
    augment /nw:networks/nw:network/nw:node/nt:termination-point:
  +--ro pm-statistics
    +--ro inbound-octets? yang:counter64
    +--ro inbound-unicast? yang:counter64
    +--ro inbound-nunicast? yang:counter64
    +--ro inbound-discards? yang:counter32
    +--ro inbound-errors? yang:counter64
    +--ro inbound-unknown-protocol? yang:counter64
    +--ro outbound-octets? yang:counter64
    +--ro outbound-unicast? yang:counter64
    +--ro outbound-nunicast? yang:counter64
    +--ro outbound-discards? yang:counter64
    +--ro outbound-errors? yang:counter64

Figure 6: Link and Termination point Level View of the hierarchies
For the data nodes of 'link' depicted in Figure 6, the YANG module defines the following minimal set of link-level performance attributes:

Percentile parameters: The module supports reporting delay and jitter metric by percentile values. By default, low percentile (10th percentile), mid percentile (50th percentile), high percentile (90th percentile) are used. Setting a percentile into 0.00 indicates the client is not interested in receiving particular percentile. If all percentile nodes are set to 0.00, this represents that no percentile related nodes will be reported for a given performance metric (e.g. one-way delay, one-way delay variation) and only peak/min values will be reported. For example, a client can inform the server that it is interested in receiving only high percentiles. Then for a given link, at a given "reference-time" "measurement-interval", the 'high-delay-percentile' and 'high-jitter-percentile' will be reported. An example to illustrate the use of percentiles is provided in Appendix A.3.

"pm-source": Indicates the performance monitoring source. The data for the topology link can be based, e.g., on BGP-LS [RFC8571]. The statistics of the VPN abstract links can be collected based upon VPN OAM mechanisms, e.g., OAM mechanisms specified in [I-D.ietf-opsawg-l3sm-l3nm], or Ethernet service OAM specified in [I-D.ietf-opsawg-l2nm]. Alternatively, the data can be based upon the underlay technology OAM mechanisms, for example, GRE tunnel OAM.

Loss Statistics: A set of loss statistics attributes that are used to measure end to end loss between VPN sites or between any two network nodes. The exact loss value or the loss percentage can be reported.

Delay Statistics: A set of delay statistics attributes that are used to measure end to end latency between VPN sites or between any two network nodes. The peak/min values or percentile values can be reported.

Jitter Statistics: A set of IP Packet Delay Variation [RFC3393] statistics attributes that are used to measure end to end jitter between VPN sites or between any two network nodes. The peak/min values or percentile values can be reported.

"protocol-type": Indicates the abstract link protocol-type of a VPN, such as GRE or IP-in-IP. The leaf refers to an identifier of the "underlay-transport" defined in [I-D.ietf-opsawg-vpn-common],...
which describes the transport technology to carry the traffic of the VPN service.

For the data nodes of 'termination-point' depicted in Figure 6, the module defines the following minimal set of statistics:

Inbound statistics: A set of inbound statistics attributes that are used to measure the inbound statistics of the termination point, such as received packets, received packets with errors, etc.

Outbound statistics: A set of outbound statistics attributes that are used to measure the outbound statistics of the termination point, such as sent packets, packets that could not be sent due to errors, etc.

5. Network and VPN Service Performance Monitoring YANG Module

The "ietf-network-vpn-pm" module uses types defined in [RFC8345], [RFC6991], and [RFC8532].

<CODE BEGINS> file "ietf-network-vpn-pm@2021-07-06.yang"
module ietf-network-vpn-pm {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm";
  prefix nvp;

  import ietf-yang-types {
    prefix yang;
    reference
      "RFC 6991: Common YANG Types";
  }
  import ietf-vpn-common {
    prefix vpn-common;
    reference
      "RFC CCCC: A Layer 2/3 VPN Common YANG Model";
  }
  import ietf-network {
    prefix nw;
    reference
      "RFC 8345: A YANG Data Model for Network Topologies, Section 6.1";
  }
  import ietf-network-topology {
    prefix nt;
    reference
      "RFC 8345: A YANG Data Model for Network Topologies, Section 6.2";
  }

import ietf-lime-time-types {
  prefix lime;
  reference
    "RFC 8532: Generic YANG Data Model for the Management of
    Operations, Administration, and Maintenance
    (OAM) Protocols That Use Connectionless Communications";
}

organization
  "IETF OPSAWG Working Group";
contact
  "Editor: Qin Wu
     <bill.wu@huawei.com>
  Editor: Bo Wu
     <lana.wubo@huawei.com>
  Editor: Mohamed Boucadair
     <mohamed.boucadair@orange.com>";
description
  "This module defines a model for Network and VPN Service Performance
  monitoring.

  Copyright (c) 2021 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 Simplified BSD License
  set forth in Section 4.c of the IETF Trust’s Legal Provisions
  Relating to IETF Documents
  (http://trustee.ietf.org/license-info).

  This version of this YANG module is part of RFC XXXX; see
  the RFC itself for full legal notices.";
revision 2021-07-06 {
  description
    "Initial revision.";
  reference
    "RFC XXXX: A YANG Model for Network and VPN Service Performance
     Monitoring";
}

identity node-type {
  description
    "Base identity for node type";
}

identity pe {
base node-type;
description
  "Identity for Provider Edge (PE) type.";
}

identity asbr {
  base node-type;
  description
  "Identity for Autonomous System Border Router (ASBR) type.";
}

identity p {
  base node-type;
  description
  "Identity for P type.";
}

identity direction {
  description
  "Base identity for measurement direction including
    one-way measurement and two-way measurement.";
}

identity one-way {
  base direction;
  description
  "Identity for one-way measurement.";
}

identity two-way {
  base direction;
  description
  "Identity for two-way measurement.";
}

typedef percentage {
  type decimal64 {
    fraction-digits 5;
    range "0..100";
  }
  description
  "Percentage.";
}

typedef percentile {
  type decimal64 {
    fraction-digits 5;
  }
}
description
  "The percentile is a statistical value that indicates that a
certain percentage of a set of data falls below it.";
}
grouping vpn-summary-statistics {
  description
  "VPN Statistics grouping used for network topology
  augmentation.";
  container vpn-summary-statistics {
    config false;
    description
    "Container for VPN summary statistics.";
    container ipv4 {
      leaf maximum-routes {
        type uint32;
        description
        "Total routes for the VPN.";
      }
      leaf total-active-routes {
        type uint32;
        description
        "Total active routes for the VPN.";
      }
      description
      "IPv4-specific parameters.";
    }
    container ipv6 {
      leaf maximum-routes {
        type uint32;
        description
        "Total routes for the VPN.";
      }
      leaf total-active-routes {
        type uint32;
        description
        "Total active routes for the VPN.";
      }
      description
      "IPv6-specific parameters.";
    }
    container mac-num {
      leaf mac-num-limit {
        type uint32;
        description
        "Maximum number of MAC addresses.";
      }
      leaf total-active-mac-num {

grouping link-error-statistics {
    description "Grouping for per link error statistics.";
    container loss-statistics {
        description "Per link loss statistics.";
        leaf packet-loss-count {
            type yang:counter64;
            description "Total received packet drops count.";
        }
        leaf packet-reorder-count {
            type yang:counter64;
            description "Total received packet reordered count.";
        }
        leaf packets-out-of-seq-count {
            type yang:counter64;
            description "Total received out of sequence count.";
        }
        leaf packets-dup-count {
            type yang:counter64;
            description "Total received packet duplicates count.";
        }
        leaf loss-ratio {
            type percentage;
            description "Loss ratio of the packets. Express as percentage of packets lost with respect to packets sent.";
        }
    }
}

grouping link-delay-statistics {
    description "Grouping for per link delay statistics";
}
container delay-statistics {
  description
  "Link delay summarised information. By default, one way measurement protocol (e.g., OWAMP) is used to measure delay.";
  leaf direction {
    type identityref {
      base direction;
    }
    default "one-way";
    description
    "Define measurement direction including one way measurement and two way measurement.";
  }
  leaf unit-value {
    type identityref {
      base lime:time-unit-type;
    }
    default "lime:milliseconds";
    description
    "Time units, where the options are s, ms, ns, etc.";
  }
  leaf min-delay-value {
    type yang:gauge64;
    description
    "Minimum delay value observed.";
  }
  leaf max-delay-value {
    type yang:gauge64;
    description
    "Maximum delay value observed.";
  }
  leaf low-delay-percentile {
    type yang:gauge64;
    description
    "Low percentile of the delay observed with specific measurement method.";
  }
  leaf middle-delay-percentile {
    type yang:gauge64;
    description
    "Middle percentile of the delay observed with specific measurement method.";
  }
  leaf high-delay-percentile {
    type yang:gauge64;
    description
    "High percentile of the delay observed with
specific measurement method;
}
}
}

grouping link-jitter-statistics {
  description
  "Grouping for per link jitter statistics";
  container jitter-statistics {
    description
    "Link jitter summarised information. By default, jitter is measured using IP Packet Delay Variation (IPDV).";
    leaf unit-value {
      type identityref {
        base lime:time-unit-type;
        default "lime:milliseconds";
        description
        "Time units, where the options are s, ms, ns, etc.";
      }
    }
    leaf min-jitter-value {
      type yang:gauge32;
      description
      "Minimum jitter value observed.";
    }
    leaf max-jitter-value {
      type yang:gauge32;
      description
      "Maximum jitter value observed.";
    }
    leaf low-jitter-percentile {
      type yang:gauge32;
      description
      "Low percentile of the jitter observed.";
    }
    leaf middle-jitter-percentile {
      type yang:gauge32;
      description
      "Middle percentile of the jitter observed.";
    }
    leaf high-jitter-percentile {
      type yang:gauge32;
      description
      "High percentile of the jitter observed.";
    }
  }
}

grouping tp-svc-telemetry {
  leaf inbound-octets {
    type yang:counter64;
    description
    "The total number of octets received on the
    interface, including framing characters.";
  }
  leaf inbound-unicast {
    type yang:counter64;
    description
    "Inbound unicast packets were received, and delivered
to a higher layer during the last period.";
  }
  leaf inbound-nunicast {
    type yang:counter64;
    description
    "The number of non-unicast (i.e., subnetwork-
broadcast or subnetwork-multicast) packets
delivered to a higher-layer protocol.";
  }
  leaf inbound-discards {
    type yang:counter32;
    description
    "The number of inbound packets which were chosen
to be discarded even though no errors had been
detected to prevent their being deliverable to a
higher-layer protocol.";
  }
  leaf inbound-errors {
    type yang:counter64;
    description
    "The number of inbound packets that contained
errors preventing them from being deliverable to a
higher-layer protocol.";
  }
  leaf inbound-unknown-protocol {
    type yang:counter64;
    description
    "The number of packets received via the interface
which were discarded because of an unknown or
unsupported protocol.";
  }
  leaf outbound-octets {
    type yang:counter64;
    description
    "The total number of octets transmitted out of the
interface, including framing characters.";
}
leaf outbound-unicast {
    type yang:counter64;
    description
        "The total number of packets that higher-level
            protocols requested be transmitted to a
            subnetwork-unicast address, including those that
            were discarded or not sent.";
}
leaf outbound-nunicast {
    type yang:counter64;
    description
        "The total number of packets that higher-level
            protocols requested be transmitted to a non-
            unicast (i.e., a subnetwork-broadcast or
            subnetwork-multicast) address, including those
            that were discarded or not sent.";
}
leaf outbound-discards {
    type yang:counter64;
    description
        "The number of outbound packets which were chosen
            to be discarded even though no errors had been
            detected to prevent their being transmitted. One
            possible reason for discarding such a packet could
            be to free up buffer space.";
}
leaf outbound-errors {
    type yang:counter64;
    description
        "The number of outbound packets that contained
            errors preventing them from being deliverable to a
            higher-layer protocol.";
}
description
    "Grouping for interface service telemetry.";
}
augment "/nw:networks/nw:network/nw:network-types" {
    description
        "Defines the service topologies types";
    container service-type {
        presence "Indicates Network service topology";
        leaf service-type {
            type identityref {
                base vpn-common:service-type;
            }
            description
                "The presence identifies the network service type,
e.g., L3VPN, VPLS, etc.

} description
"Container for VPN service type."

} augment "/nw:networks/nw:network" {
when 'nw:network-types/nvp:service-type' {
 description
"Augment only for VPN Network topology."
}
description
"Augment the network with service topology attributes"
container vpn-pm-attributes {
 leaf vpn-id {
  type vpn-common:vpn-id;
  description
  "VPN identifier."
 }
 leaf vpn-service-topology {
  type identityref {
    base vpn-common:vpn-topology;
  }
  description
  "VPN service topology, e.g., hub-spoke, any-to-any,
   hub-spoke-disjoint";
 }
 description
"Container for vpn topology attributes."
}

} augment "/nw:networks/nw:network/nw:node" {
 description
"Augment the network node with other general attributes"
 container pm-attributes {
  leaf node-type {
    type identityref {
      base node-type;
    }
    description
    "Node type, e.g., PE, P, ASBR."
  }
    description
    "Container for node attributes."
  }
}
augment "/nw:networks/nw:network/nw:node/pm-attributes" {
    when '../nw:network-types/nvp:service-type' {
        description
        "Augment only for VPN node attributes.";
    }
    description
    "Augment the network node with VPN specific attributes";
    leaf role {
        type identityref {
            base vpn-common:role;
        }
        default "vpn-common:any-to-any-role";
        description
        "Role of the node in the VPN.";
    }
    uses vpn-summary-statistics;
}

augment "/nw:networks/nw:network/nt:link" {
    description
    "Augment the network topology link with performance monitoring
    attributes";
    container pm-attributes {
        description
        "Container for PM attributes.";
        leaf low-percentile {
            type percentile;
            default "10.00";
            description
            "Low percentile to report. Setting low-percentile
            into 0.00 indicates the client is not interested in receiving
            low percentile.";
        }
        leaf middle-percentile {
            type percentile;
            default "50.00";
            description
            "Middle percentile to report. Setting middle-percentile
            into 0.00 indicates the client is not interested in receiving
            middle percentile.";
        }
        leaf high-percentile {
            type percentile;
            default "90.00";
            description
            "High percentile to report. Setting high-percentile
            into 0.00 indicates the client is not interested in receiving
            high percentile";
leaf pm-source {
    type string;
    config false;
    description
        "The OAM tool used to collect the PM data.";
}

leaf reference-time {
    type yang:date-and-time;
    config false;
    description
        "The time that the current Measurement Interval started.";
}

leaf measurement-interval {
    type uint32;
    units "seconds";
    default "60";
    config false;
    description
        "Interval to calculate performance metric.";
}

container pm-statistics {
    config false;
    uses link-error-statistics;
    uses link-delay-statistics;
    uses link-jitter-statistics;
    description
        "Container for service telemetry attributes.";
}

augment "/nw:networks/nw:network/nt:link/pm-attributes" {
    when '../../nw:network-types/nvp:service-type' {
        description
            "Augment only for VPN Network topology.";
    }
    description
        "Augment the network topology link with service performance
         monitoring attributes";
    leaf protocol-type {
        type identityref {
            base vpn-common:protocol-type;
        }
        config false;
        description
            "Underlay-transport type, e.g., GRE, LDP, etc.";
    }
}
augment "/nw:networks/nw:network/nw:node/nt:termination-point" {
  description
    "Augment the network topology termination point with
    performance monitoring attributes";
  container pm-statistics {
    config false;
    uses tp-svc-telemetry;
    description
      "Container for termination point PM attributes.";
  }
}

6. Security Considerations

The YANG modules defined in this document MAY be accessed via the
RESTCONF protocol [RFC8040] or NETCONF protocol [RFC6241]. The
lowest RESTCONF or NETCONF layer requires that the transport-layer
protocol provides both data integrity and confidentiality, see
Section 2 in [RFC8040] and [RFC6241]. 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 NETCONF access control model [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. These are the subtrees and data nodes
and their sensitivity/vulnerability:

7. IANA Considerations

This document requests IANA to register the following URI in the "ns" subregistry within the "IETF XML Registry" [RFC3688]:

    Registrant Contact: The IESG.
    XML: N/A, the requested URI is an XML namespace.

This document requests IANA to register the following YANG module in the "YANG Module Names" subregistry [RFC6020] within the "YANG Parameters" registry.

    Name:         ietf-network-vpn-pm
    Maintained by IANA: N
    Prefix:       nvp
    Reference:    RFC XXXX

8. Acknowledgements

Thanks to Joe Clarke, Adrian Farrel, Greg Mirsky, Roque Gagliano, Erez Segev, and Dhruv Dhody for reviewing and providing important input to this document.

9. Contributors

    Michale Wang
    Huawei
    Email: wangzitao@huawei.com

    Roni Even
    Huawei
    Email: ron.even.tlv@gmail.com

10. References

10.1. Normative References

[I-D.ietf-opsawg-vpn-common]


10.2. Informative References


Appendix A. Illustrating Examples

A.1. Example of Pub/Sub Retrieval

The example shown in Figure 7 illustrates how a client subscribes to the performance monitoring information between nodes ('node-id') A and B in the L3 network topology. The performance monitoring parameter that the client is interested in is end-to-end loss.

```xml
<rpc netconf:message-id="101"
 xmlns:netconf="urn:ietf:params:xml:ns:netconf:base:1.0">
 <establish-subscription
 xmlns="urn:ietf:params:xml:ns:yang:ietf-subscribed-notifications">
  <stream-subtree-filter>
   <networks
    xmlns="urn:ietf:params:xml:ns:yang:ietf-network-topo">
    <network
     xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
     <network-id>l3-network</network-id>
     <service-type
      xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
      L3VPN
     </service-type>
     <node
      xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
      <node-id>A</node-id>
      <pm-attributes
       xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
       <node-type>pe</node-type>
      </pm-attributes>
     </node>
    </network>
   </networks>
  </stream-subtree-filter>
 </establish-subscription>
</rpc netconf:message-id="101">
```
</pm-attributes>
<termination-point
<tp-id>1-0-1</tp-id>
<pm-statistics
xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
<inbound-octets>150</inbound-octets>
$outbound-octets>100</outbound-octets>
</pm-statistics>
</termination-point>
</node>

<node>
<node-id>B</node-id>
<pm-attributes
xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
<node-type>pe</node-type>
</pm-attributes>
<termination-point
<tp-id>2-0-1</tp-id>
<pm-statistics
xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
<inbound-octets>150</inbound-octets>
$outbound-octets>100</outbound-octets>
</pm-statistics>
</termination-point>
</node>

<link
<link-id>A-B</link-id>
<source>
<source-node>A</source-node>
</source>
<destination>
<dest-node>B<dest-node>
</destination>
<protocol-type>mpls-te</protocol-type>
<pm-attributes
xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
<loss-statistics>
(packet-loss-count>100</packet-loss-count>
</loss-statistics>
</pm-attributes>
</link>
This example, depicted in Figure 8, illustrates how a the client can use the RPC model to fetch performance data on demand. For example, the client requests "packet-loss-count" between 'source-node' A and 'dest-node' B that belong to the same VPN ('VPN1').

```xml
<rpc xmlns="urn:ietf:params:xml:ns:netconf:base:1.0" message-id="1">
  <report xmlns="urn:ietf:params:xml:ns:yang:example-service-pm-report">
      <network>
        <network-id>vpn1</network-id>
        <node>
          <node-id>A</node-id>
          <pm-attributes xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
            <node-type>pe</node-type>
          </pm-attributes>
          <termination-point xmlns="urn:ietf:params:xml:ns:yang:ietf-network-topology">
            <tp-id>1-0-1</tp-id>
            <pm-statistics xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
              <inbound-octets>100</inbound-octets>
              <outbound-octets>150</outbound-octets>
            </pm-statistics>
          </termination-point>
        </node>
        <node>
          <node-id>B</node-id>
          <pm-attributes xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
            <node-type>pe</node-type>
          </pm-attributes>
          <termination-point xmlns="urn:ietf:params:xml:ns:yang:ietf-network-topology">
            <tp-id>2-0-1</tp-id>
            <pm-statistics xmlns="urn:ietf:params:xml:ns:yang:ietf-network-vpn-pm">
              <inbound-octets>150</inbound-octets>
              <outbound-octets>200</outbound-octets>
            </pm-statistics>
          </termination-point>
        </node>
      </network>
    </networks>
  </report>
</rpc>
```
A.3. Example of Percentile Monitoring

The following shows an example of a percentile measurement for a VPN link.
{ "ietf-network-topology:link": { "link-id":"vpn1-link1", "source":{ "source-node":"vpn-node1" }, "destination":{ "dest-node":"vpn-node3" }, "ietf-network-vpn-pm:protocol-type":"gre", "ietf-network-vpn-pm:pm-attributes":{ "low-percentile":"20.00", "middle-percentile":"50.00", "high-percentile":"90.00", "pm-statistics:delay-statistics":{ "direction":"one-way", "unit-values":"milliseconds", "min-delay-value":"43", "max-delay-value":"99", "low-delay-percentile":"64", "middle-delay-percentile":"77", "high-delay-percentile":"98" } } } }

Authors’ Addresses

Bo Wu (editor)
Huawei
101 Software Avenue, Yuhua District
Nanjing, Jiangsu 210012
China
Email: lana.wubo@huawei.com

Qin Wu (editor)
Huawei
101 Software Avenue, Yuhua District
Nanjing, Jiangsu 210012
China
Email: bill.wu@huawei.com
Abstract

This document identifies the importance and use cases of source address validation (SAV) at both intra-AS level and inter-AS level (see [RFC5210]). However, existing intra-AS and inter-AS SAV mechanisms, either Ingress ACL filtering [RFC2827], unicast Reverse Path Forwarding (uRPF) [RFC3704], or Enhanced Feasible-Path uRPF (EFP-uRPF) [RFC8704] has limitations in scalability or accuracy. This document provides the gap analysis of the existing SAV mechanisms followed with some design considerations.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

Status of This Memo

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This Internet-Draft will expire on 28 April 2022.
1. Introduction

Source Address Validation (SAV) is important for defending against source address forgery attacks and accurately tracing back to the attackers [RFC5210]. Consider that the Internet is extremely large and complex. It is much difficult to solve the source address spoofing problem at a single "level" or through a single SAV mechanism. On the one hand, it is unrealistic to require all networks to deploy a single SAV mechanism. On the other hand, the failure of a single SAV mechanism will completely disable SAV.

To address the issue, Source Address Validation Architecture (SAVA) was proposed [RFC5210]. According to the operating feature of the Internet, SAVA presents a hierarchical architecture which carries out source IP address validation at three checking levels, i.e., access network, intra-AS, and inter-AS. Different levels provide different
granularities of source IP address authenticity. In contrast to the single-level/point model, SAVA allows incremental deployment of SAV mechanisms while keeps effective because of its multiple-fence design. So, enhancing the source IP address validity in all the three checking levels is of high importance. Furthermore, one or more independent and loosely-coupled SAV mechanisms can coexist and cooperate under SAVA, which is friendly to different users (e.g., providers) with different policies or considerations. Obviously, the quality of SAV mechanisms for their target checking levels is key to the performance of SAV.

There are many SAV mechanisms for different checking levels. For the access network level, Source Address Validation Improvement (SAVI) was proposed to force each host to use legitimate source IP address [RFC7039]. SAVI acts as a purely network-based solution without special dependencies on hosts. It dynamically binds each legitimate IP address to a specific port/MAC address and verifies each packet's source address through the binding relationship. One of the most attractive features of SAVI is that it supports the maximally fine granularity of individual IP addresses, which is much finer than the previous ingress filtering mechanisms.

At the intra-AS level, static Access Control List (ACL) is a typical solution of SAV. Operators can configure some matching rules to specify which kind of packets are acceptable (or unacceptable). The information of ACL should be updated manually so as to keep consistent with the newest filtering criteria, which inevitably limits the flexibility and accuracy of SAV. Loose unicast Reverse Path Forwarding (uRPF) is another solution suitable to intra-AS SAV [RFC8704]. The routers deploying loose uRPF accept any packets whose source addresses appear in the local FIB tables. Due to the loss of directionality, loose uRPF may induce false negative problems. Strict uRPF was proposed with the consideration of directionality [RFC8704]. Routers deploying strict uRPF accepts a data packet only when i) the local FIB contains a prefix encompassing the packet's source address and ii) the corresponding forwarding action for the prefix matches the packet's incoming interface. Otherwise, the packet will be dropped. However, in the scenarios (e.g., multihoming cases) where data packets are under asymmetric routing, strict uRPF often results in serious false positive problem [RFC8704].
At the inter-AS level, a combination of Enhanced Feasible-Path uRPF (EFP-uRPF) and loose uRPF is recommended in [RFC8704]. Particularly, EFP-uRPF is suggested to be applied on customer interfaces. EFP-uRPF on an AS can prevent its customers spoofing its upstream ASes’ source addresses but fails in the case of two customers spoofing each other. On lateral peer interfaces and transit provider interfaces, loose uRPF is taken. As described previously, false negative problems may arise.

SAVI provides a complete and maximally fine-grained access validation, but it is impossible to deploy SAVI on every access point in the universe. The "fences" at intra- and inter-AS levels are much important for filtering source address forgery packets that are let go by access networks. However, there exist some instinctive drawbacks in the existing SAV mechanisms designed for both the intra- and inter-AS levels, which leads to inevitable false negative or false negative problems. A more complete SAV mechanism is required for both intra- and inter-AS levels.

This document identifies the use cases of intra- and inter-AS SAVs. These cases will help analyze the instinctive drawbacks of the existing SAV mechanisms. After that, some design considerations of overcoming the drawbacks will be presented.

2. Terminology

False positive means the legitimate data packets are dropped unexpectedly. False negative indicates that the data packets with spoofed source IP addresses fail to be filtered.

Intra-AS SAV denotes the SAV at intra-AS level, which checks the source address validity of the data packets (i.e., EAST-WEST traffic) within an AS. Intra-AS SAV can prevent hosts/routers from spoofing other source IP blocks in the same AS.

Inter-AS SAV denotes the SAV at inter-AS level, which verifies the authenticity of the source address of incoming traffic (i.e., NORTH-SOUTH traffic). Particularly, the traffic arriving from the customer AS is Northward traffic. The traffic received from the provider/peer AS is Southward traffic.

Two types of SAV modes are defined, i.e., allowlist and blocklist. Both of them can be applied to one or more specified interfaces of a device (router or switch). The data packets with source addresses appearing in the allowlist and entering the device at the interface specified by the allowlist will be accepted. The device will drop the data packets that i) are with source addresses not included in the allowlist or ii) are with legal source addresses but enter the
device at wrong interfaces. The SAV tables of all uRPF-like mechanisms belong to allowlist. On the contrary, blocklist only focus on validity of the source addresses included in the list. Specifically, the data packets with source addresses included in the blocklist will be dropped if the arrival interfaces are not expected. Otherwise, they will be accepted. As for the data packets with source addresses not included in the blocklist, the device will accept them all the time, which is the main difference from the SAV mode of allowlist. Since allowlist and blocklist can work on specified interfaces of a device, the decision on the SAV mode choice can be made for an interface adaptively.

3. Use Cases

Figure 1 illustrates the requirements of SAV in both intra- and inter-AS levels. AS1-AS5 belong to the same customer cone, and AS1 is the stub AS. The topology of AS2 is presented while other ASes’ inner structures are hidden for brevity.
3.1. Use Case 1: Intra-AS SAV

In some scenarios especially very large ASes, hosts/routers in the same AS may spoof each other’s IP addresses. In Figure 1, Router2 spoofs P1 that originates from Router3. With Intra-AS SAV, EAST-WEST traffic can be checked, and source address spoofing attacks can be prevented. In the figure, Router1, Router3, and Router4 will drop the packets with P1’ while accept those with P1, when they deploy Intra-AS SAV mechanisms. Overall, Intra-AS SAV can prevent the source address spoofing from the same AS.
3.2. Use Case 2: Inter-AS SAV

In Figure 1, AS4 spoofs AS2’s IP address prefix, i.e., P1 originated from Router3. AS5 will receive the Northward traffic from AS2 and AS4 with legitimate and spoofed IP addresses, respectively. An SAV mechanism is necessary for AS5 to drop the illegal traffic. From the viewpoint of Southward traffic, AS1 may also receive spoofed traffic from AS3 (if AS3 accepts the data packets with source prefix P1*). So, the deployment of SAV on AS1 is also important. Overall, Inter-AS SAV is necessary and can improve the confidence of the source IP address validity among ASes.

Furthermore, most of the existing mechanisms applied to Intra-AS or Inter-AS SAV only take the manner of allowlist. However, an allowlist may result in false positive when a legitimate IP address does not appear in the allowlist. That is, allowlist can be incomplete.

In contrast, blocklist can avoid false positive in some way as it only drop illegal packets currently known by it, even though incomplete blocklist may result in false negative. The choice between allowlist and blocklist is important for improving the accuracy of SAV.

4. Gap Analysis

High accuracy is the basic requirement of any intra- or inter-AS SAV mechanism. For any SAV mechanism, false positive must be avoided because legitimate traffic must not be influenced. On that basis, SAV should also reduce false negative as much as possible. However, existing SAV mechanisms can not well meet these requirements.

4.1. Existing Intra-AS SAV mechanisms

Operators can configure static ACLs on border nodes to validate source addresses. The main drawback of ACL-based SAV is high operational overhead. Limited application scenarios make the ACL-based method unable to do sufficient SAV on EAST-WEST traffic.

Strict uRPF can generate SAV tables automatically, but it also has limited application scenarios. Figure 2 illustrates an intra-AS SAV scenario. In the scenario, AS1 runs strict uRPF. An access network having IP address prefix 10.0.0.0/15 is attached to two border routers (Router1 and Router2) of AS1. Due to customer’s policy, it advertises 10.0.0.0/16 to Router1 and 10.1.0.0/16 to Router2. Then, Router1 and Router2 will advertise the learned IP address prefixes to other routers in AS1 through intra-domain routing protocols such as OSPF and IS-IS.
Although customer only advertises 10.0.0.0/16 to Router1, it may send packets with source IP addresses belonging to 10.1.0.0/16 to Router1 due to load balancing requirements. Suppose the destination node is Router5. Then the path to destination is Customer->Router1->Router3->Router5, while the reverse path is Router5->Router4->Router2->Customer. The round trip routing path is asymmetric, which cannot be dealt with well by strict uRPF.

Specifically speaking, strict uRPF is faced with the false positive problem under asymmetric routing scenarios. When Router1/Router3 runs strict uRPF, it learns SAV rules that packets with source address prefix of 10.0.0.0/16 should enter the router on interface ‘#’. Note that strict uRPF takes allowlist in which the rule <10.0.0.0/16,interface ‘#’> is maintained. When the packets with source addresses of 10.1.0.0/16 arrive, they will be dropped, which results in false positive. Similarly, when strict uRPF is deployed on Router2, the false positive problem still exists.

```
+-----------------------------------+
|  AS1      +----------+            |
|           | Router 5 |            |
|           +----------+            |
|             /      \              |
|            /        \             |
|  +----------+      +----------+   |
|  | Router 3 |------| Router 4 |   |
|  +----#-----+      +----------+   |
|       |                 |         |
|       |                 |         |
|  +----------+      +----------+   |
|  | Router 1 |      | Router 2 |   |
|  +----#-----+      +----------+   |
|       \                 /         |
+--------\---------------/----------+

<table>
<thead>
<tr>
<th>10.0.0.0/16  10.1.0.0/16</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>access network</th>
</tr>
</thead>
</table>
```

Figure 2: An intra-AS SAV scenario
4.2. Existing Inter-AS SAV mechanisms

The most popular inter-AS SAV is suggested by [RFC8704], which combines EFP-uRPF algorithm B and loose uRPF. In particular, EFP-uRPF algorithm B is for Northward traffic validation. It sacrifices the directionality of customer interfaces for reducing false positive cases [RFC8704]. Loose uRPF is for validating Southward traffic on lateral peer and transit provider interfaces. It sacrifices directionality of Southward traffic completely. Such a combined method sacrificing directionality will lead to false negative sometimes.

Figure 3 illustrates an inter-AS SAV scenario where the above inter-AS SAV method will fail. In the figure, there are two customer ASes, i.e., AS1 and AS2. Both of them are attached to a provider AS, i.e., AS4. AS4 has a lateral peer and a provider, i.e., AS3 and AS5. Particularly, AS1 has IP address prefix P1 and advertises it to AS4. IP address prefix P2 is allocated to AS2 and is also advertised to AS4. AS3 has IP address prefix P3 and AS5 has IP address prefix P5. P3 and P5 are also advertised to AS4 through BGP. AS4 deploys SAV policies, i.e., a combination of EFP-uRPF algorithm B and loose uRPF.

Figure 3: An inter-AS SAV scenario
For Northward traffic, AS4 applies EFP-uRPF. Under EFP-uRPF, AS4 will generate allowlists considering P1 and P2 are legitimate on both the two customer interfaces. When AS1 spoofs IP address prefix P2 of AS2, the malicious Northward traffic cannot be filtered by AS4. The same is true when AS2 forges P1 of AS1. That is to say, EFP-uRPF cannot prevent source address spoofing among customers even though it only focus on Northward traffic.

For Southward traffic, AS4 deploys loose uRPF for the interfaces of AS3 and AS5. It will learn that the packets with source addresses of P3 or P5 can be accepted without validating the specific arrival interface. Since loose uRPF loses directionality completely, it obviously will fail in dealing with the source address spoofing between its lateral peer and provider, i.e., AS3 and AS5.

The instinctive drawbacks of uRPF-like SAV mechanisms come from the dependence on local FIB and RIB. Local FIB and RIB roughly describe the relationship among customers, providers, and lateral peers, which inherently cannot completely restore directionality information of network traffic. The mismatching of advertised routing information and real data path (e.g., asymmetric routing) will do reduce the accuracy of source address validation.

5. Design Considerations

The key to address the instinctive drawbacks of existing intra- and inter-AS SAV mechanisms is to overcome the limitations of advertised routing information (expressed as RIB and FIB). That is to say, SAV should follow the real data forwarding path. To this end, a path probing method can be taken. Particularly, a router (called a start router) can proactively send probing packets carrying source addresses originated locally to all the destinations known by the router. These packets will be forwarded to each destination along the real forwarding paths. Routers along the forwarding paths will relay these packets. At the same time, these traversed routers learn the pair <source address prefix, interface> information for the start router and could generate SAV tables based on such information. SAV tables will be used to filter packets to prevent spoofing IP addresses originated from the start router.
The goal of the design is to achieve zero false positive while trying best to reduce false negative in both Intra-AS and Inter-AS SAVs. In practice, it cannot be guaranteed that complete forwarding information is always learned from all interfaces. Therefore, a combination of allowlist and blocklist is an alternative way to improve the accuracy of SAV. If an interface is able to learn the complete forwarding information, allowlist is fine. Otherwise, blocklist would be better than allowlist since the former only validates the legality of learned address information.

Besides high accuracy, designing a practical SAV mechanism needs to consider many practical issues:

* High scalability. The design should not induce much overhead (e.g., bandwidth cost of path probing). A fast convergence performance under environment changes is also important for improving the scalability in different scales of networks.

* High deployability. SAV tables should be generated automatically to reduce the operational cost in practice. A strategy of incremental deployment also needs to be considered.

* High security. The design should include mechanisms to guarantee the integrity of probing packets. The path probing-based SAV should be free of Man-in-the-Middle Attack.

6. Security Considerations
   TBD

7. Contributors
   TBD

8. Acknowledgments
   TBD

9. Normative References


Authors’ Addresses

Dan Li
Tsinghua
Beijing
China

Email: tolidan@tsinghua.edu.cn

Jianping Wu
Tsinghua
Beijing
China

Email: jianping@cernet.edu.cn

Mingqing Huang
Huawei
Beijing
China

Li, et al. Expires 28 April 2022
Abstract

This document motivates and specifies a data model for lifecycle management and operations. It describes the motivation and requirements to collect asset-centric metrics including but not limited to asset adoption and usability, licensing, supported features and capabilities, enabled features and capabilities, etc.; with the primary objective to measure and improve the overall user experience along the lifecycle journey, from technical requirements and technology selection through advocacy and renewal, including the end of life of an asset.

Status of This Memo

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1. Introduction

The virtualization of hardware assets and the development of applications using microservice architecture for cloud-native infrastructure created new consumption and licensing models. Any service can be deployed by composing multiple assets together where an asset refers to hardware, software, application, system or service. For example, cloud-native infrastructure from one vendor may be hosted on the physical server from another vendor or a combination of multiple cloud-native functions from one or more vendors can be combined to execute any service.

This introduces challenges for both lifecycle and adoption management of the assets. For example, a user may need to identify the capability availability of different assets or measure the usage of each capability (or the combination) from any specific asset to measure its optimal potential. Moreover, the user could pinpoint the reason: the software application could not be optimally deployed, or is not simple to use, or is not well documented, etc. The user may use feed such measurements and analysis metrics back to the support engineers and the developers, so they can focus their work effort only on features that users are adopting, or even determine when the lifecycle of the development could end.

This creates the need to collect and analyze asset-centric lifecycle management and operations data. From now on this data will be referred as Lifecycle Management and Operations (LMO); where LMO is not limited to virtualized or cloud environments, it covers all types of networking environments in which technology assets are deployed.

LMO data constitutes data needed to measure asset-centric lifecycle metrics including but not limited to asset adoption and usability, licensing, supported features and capabilities, enabled features and capabilities, etc. The primary objective is to facilitate the asset lifecycle management from the initial asset selection and positioning, licensing, feature enablement and usage, and beyond renewal to improve the overall user experience.

The main challenge in collecting LMO-related data, especially in a multi-vendor environment, relies on the ability to produce and consume such data in a vendor-agnostic, consistent and synchronized manner. APIs or telemetry are meant to collect and relay this data to receiving equipment for storing, analysis and/or visualization.
This document describes the motivation behind LMO, lists use cases, followed by the information model and data model of LMO. The list of use cases describes the need for new functional blocks and their interactions. The current version of this draft is focused on asset inventory, licenses information, feature usage and incident management. This draft specifies four YANG modules [RFC7950] focused on LMO, including:

* Licenses,
* Assets,
* Usage level of Asset features, and
* Incident Management.

This document is organized as follows. Section 2 establishes the terminology and abbreviations. In Section 3, the goals and motivation of LMO are discussed. In Section 4, use cases are introduced. Section 5 specifies the information model and the data models for LMO.

1.1. 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 BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Terminology

Terminology and abbreviations used in this document:

* Asset: refers to hardware, software, applications, or services. An asset can be physical or virtual.
* Consumer: refers to an entity that utilizes the outcomes of LMO. A consumer can be a user, a developer or some other interested third party.
* Developer: refers to the entity that creates or develops the entire asset or the part of the asset.
* EOL: End of Life.
* Features: are options or functional capabilities available in an asset.
* License: is issued by an entity such as the developer or the Open Source community and allows the user to operate the asset. Licenses determine how the asset can be leveraged and what is required in cases the asset is changed.

* LMO: Lifecycle Management and Operations.

* Optimal Software Version(OSV): refers to the elected software version considered optimal in the user environment.

* PID: Product Identifier.

* Usage: refers to how features of the asset are used.

* User: refers to the organization that owns or consumes the asset. Within the organization there are entities that: a) use the assets in their operations, b) manage the assets.

* User Experience: how a user interacts with and experiences a particular asset. It includes a user’s perceptions of ease of use, efficiency, and utility of an asset.

3. Motivation

The user experience with a specific asset can be organized into four classes:

1. Asset characteristic class, covering anything related to asset, license, features, etc.

2. Utilization class, to measure how the assets and features are used, duration of usage, uptime, etc.

3. Notification class, covering any security advisory, retirement, etc.

4. Incident class, to record and report any problem the user has faced with the asset.

The ability to measure, produce and consume LMO could benefit the user organization in addressing issues such as:

* Licenses may not have been obtained at the optimum level for a given feature, where a user might have bought licenses that are not activated.

* Features of an asset might not be used as needed in all deployments within the organization.
Resolution of incidents involving the asset and the developer of the technology used within the asset.

In addition to the resolution of incidents, LMO could allow developer organizations to optimize the features they offer. For example, they could consider deprecating features that are used infrequently or focus on introducing more features for the assets that are widely deployed in various infrastructures.

LMO also covers the need of communication between users and the developer. LMO can provide the capability for users to provide feedback about any asset (e.g., potential deficiency of a feature, feature enhancement request). An administrator in the user organization may include specific metrics that identify a potential problem of that specific feature or a capability of the asset. An engineer in the developer organization can determine the impact of the potential deficiency from the number of users providing feedback. Note that this channel is different from a "call to a Technical Assistance Center" in which the user may request help in resolving operational issues with the asset.

4. Use Cases

4.1. License Inventory and Activation

An operations engineer would like to understand which licenses are activated and which are used and/or consumed. It is also important for asset users to understand which features within their assets might need a license and how to activate them.

It is relatively straightforward to have an inventory of existing licenses when there is only one asset developer (providing the asset) and one asset family.

But complexity grows when there are many different developers, systems and processes involved. New service offerings have introduced new attributes and datasets and require alignment with new business models (pay-per-product, subscription model, pay-as-you-go model, etc.). They might support different license types and models: asset activation keys, trust-based model, systems that act as proxy from the back end owned by the asset developer to support the control of licenses, etc.
Sometimes it is a challenge to report which licenses have been bought by the asset user, or who in the user organization owns that license because that information might rely on different asset developers; even within the same asset developer, licenses may correspond to different types or groups of assets. Asset users often need to interact with different license systems and processes.

Information on how assets are licensed could be delivered from a combination of attributes such as: sales order, purchase order, asset activation key, serial number, etc.

If there is no consistency on how to deal with those data points, complexity increases for the consumer, potentially requiring manual steps. Automating those manual steps or exceptions becomes time-consuming, eventually leading to higher costs for the asset consumer.

Having a common data model for LMO eases the integration between different data sources, processes, and consolidation of the information under a common reference.

4.2. Features in Use

Feature logic is required to identify the configured features from the running configuration and determine how they might be used. There is often a lack of an easy method to list any configured features available in the current asset.

This information is extracted from the running configuration many times, implemented by a rule system without having an easy method to list any configured features available in the current asset.

Some of these use cases need to be built on top of others, and from them, other more complex use cases could be created. For instance, Software Compliance use cases can be automated, based on use cases like security advisory, errata, End of Life(EOL), etc.

All this brings a complete set of use cases that fulfills Lifecycle Management of assets, complementing and providing metrics on how asset users are using assets and how their experience from using those assets can be improved.
4.3. Assets in Use

Current approach to quantify how an asset is used, requires volume or aggregated usage/consumption metrics related to deployed assets, functions, features, integrations, etc. Also the need to quantify which metrics might be associated to a user, an organization, to specific services and how often are used; while others may be based on pre agreed profile (contractual or usage) of intended use. Examples include:

* Number of search/queries sent by the user.
* Amount of data returned to the user.
* Amount of active time spent using the asset/feature.
* Number of concurrent users accessing the asset/feature.
* Number of features in use.
* Number of users or sites using those features, etc.

The information models and data models for LMO include data fields to support metrics that might be required by consumption-based charging and licensing of asset usage.

4.4. Risk Mitigation Check (RMC)

Network, software and cloud engineers would like to be aware of known issues that are causing assets to crash so that they can act to remediate the issue quickly, or even prevent the crash if alerts are triggered on time. There are analytics tools that can process memory core dumps and crash-related files, providing the ability to the asset developers to determine the root cause.

Accordingly, asset users can remediate the problem, automate the remedy to enable incident deflection, allowing the support staff to focus on new problems. The goal of introducing normalization is not to define attributes for each of the elements being part of the crash information, but the results of RMC should be normalized and registered.

Risk Mitigation Check could also include the possibility to be aware of current and historical restarts allowing network and software engineers to enhance the service quality to asset users.
4.5.  Errata

Both hardware and software critical issues or Errata need development to automate asset user matching:

* Hardware Errata match on product identifiers (PIPs) + serial numbers along with additional hardware attributes.
* Software Errata match on software type and software version along with some additional device attributes.

Engineering might develop the logic to check whether any critical issue applies to a single serial number or a specific software release.

The information to be correlated includes customer identification, license, and asset information that the asset user might own. All this information needs to be correlated with hardware and software Errata, and EOL information to show which part of the asset inventory might be affected.

4.6.  Security Advisory

The Security Advisory use case automates the matching of asset user data to security bulletins published by asset developers. Security Advisory logic implemented by developers could apply to a specific software release.

4.7.  Optimal Software Version (OSV)

The objective of the Optimal Software Version (OSV) use case is that consumers can mark software images as OSV for their assets; based on this, it is easier for them to control and align their hardware and software assets to the set of OSVs.

Based on the logic of OSV, use cases like software compliance, risk trend analysis, acknowledge bugs, security advisories, errata, what-if analysis, etc., could be realized.

4.7.1.  Software Conformance

All the assets should be at their latest recommended software version in case a security update is required to address a security issue of a specific feature.

The Software Conformance use case provides a view to the asset users and informs the users whether the assets that belong to a specific group conforms to the OSV or not. It can provide the users with a
report, including a representation of software compliance for the entire network and software applications. This report could include the current software version running on the asset and the recommended software version. The report could enable users to quickly highlight which group of assets might need the most attention to inspire appropriate actions.

The Software Conformance use case uses data that might not be provided by the asset itself. Data needs to be provided and maintained also by the asset developers, through e.g., asset catalog information. Similar logic applies to a feature catalog, where the asset developer maintains the data and updates it adequately based on existing bugs, security advisories, etc.

The Software Conformance process needs to correlate the Software catalog information with the software version running on the asset.

4.7.2. Risk Trend Analysis

The Risk Trend Analysis use case provides customers with a risk trend analysis, summarizing what might change before applying changes, including registered bugs, security advisories and errata.

4.7.3. What-if Analysis

The What-if Analysis use case allows asset users to plan for new hardware or software, giving them the possibility to change the config parameters or model how new hardware or software might change the software suggestions generated by OSV.

OSV and the associated use cases involve dependencies on attributes that might need to be collected from assets directly, including related inventory information (serial numbers, asset identifiers, software versions, etc.), but also dynamic information could be required, like:

* Information on features that might be enabled on the particular asset.

* Catalogs, that might include information related to release notes. For example, consider a feature catalog. This catalog could include software versions that support a specific feature; the software releases that a feature is supported in; or the latest version that a feature is supported in, in case the feature is EOL.

* Data sources to correlate information coming from reports on critical issues or errata, security advisory, End of Life, etc.
Those catalogs and data sources with errata information, EOL, etc. need to be maintained and updated by asset developers, making sure that the software running on the assets is safe to run and up to date.

4.8. Asset Retirement - End of Life (EOL)

Hardware EOL reports need to map Hardware EOL PIDs, focusing on base PIDs so that bundles, spares, non-base PIDs, etc., do not provide false EOL reporting to asset users. Software EOL reports are used to automate the matching of user software type and software version to software EOL bulletins.

5. Information Model

The broad metric classes defined in section 3 that quantify user experience can be modeled as shown in Figure 1. There is an inventory of all assets that the user possesses. Each asset in the inventory may be entitled to one or more licenses; a license may contain one or more sub-licenses. The level of usage for each feature and license associated with the asset is measured. For every asset, a list of incidents could be created.

For example, a user needs to measure the utilization of a specific license for a specific type of asset. The information about the license may reside in a license server. The state (activated or not) of the license may reside with the asset itself or a proxy. They can be aggregated/correlated as per the information model shown in Figure 1 to give information to the user regarding the utilization of the licenses. The user experience is thus enhanced by having accurate knowledge about the utility of the given license.
The model allows for future expansion by new metrics that will quantify user experience. Notice that future association relationship and future expansion might be linked to asset or to one of the other datasets: incident, feature usage or licenses.

6. Data Models

6.1. Tree Diagrams of the modules that form LMO

6.1.1. Aggregated Asset Inventory

This specification uses [I-D.draft-ietf-netmod-geo-location-11], [I-D.draft-ietf-opsawg-sbom-access-03]

module: ietf-lmo-assets-inventory
  +--ro capture-info
    |   +--ro collected-on? yang:date-and-time
    |   +--ro collected-from? string
  +--ro assets
    |   +--ro asset* [id]
      |       +--ro id lcom:asset-id
++-ro vendor?            lmocom:vendor-id
++-ro pid?                string
++-ro serial-number?      string
++-ro vid?                string
++-ro mac-address?        yang:mac-address
++-ro ip-address*         inet:ip-address
++-ro entity-name?        string
++-ro product-description? string
++-ro udi?                string
++-ro transparency-info?  inet:uri
++-ro type?               identityref
++-ro subtype?            identityref
++-ro role?               identityref
++-ro aggregation?        boolean
++-ro number-of-instances? uint32
++-ro platform-dependency-os? identityref
++-ro install-location
    ++-ro geo-location
        ++-ro reference-frame
            ++-ro alternate-system? string {alternate-systems}?
            ++-ro astronomical-body? string
            ++-ro geodetic-system
                ++-ro geodetic-datum? string
                ++-ro coord-accuracy? decimal64
                ++-ro height-accuracy? decimal64
            ++-ro (location)?
                ++-:(ellipsoid)
                    ++-ro latitude?    decimal64
                    ++-ro longitude?   decimal64
                    ++-ro height?      decimal64
                ++-:(cartesian)
                    ++-ro x?           decimal64
                    ++-ro y?           decimal64
                    ++-ro z?           decimal64
            ++-ro velocity
                ++-ro v-north?   decimal64
                ++-ro v-east?    decimal64
                ++-ro v-up?      decimal64
            ++-ro timestamp?     yang:date-and-time
            ++-ro valid-until?  yang:date-and-time
        ++-ro deployment-mode?  identityref
        ++-ro activation-date? yang:date-and-time
        ++-ro software-version? string
    ++-ro hotfixes
        ++-ro hotfix* []
            ++-ro version? identityref
            ++-ro order?    uint8
        ++-ro software-type?  string
6.1.2. Licenses

module: ietf-lmo-licenses
  +--ro capture-info
      |---ro collected-on?     yang:date-and-time
      |---ro collected-from?   string
  +--ro licenses
      +--ro license* [id]
          +--ro id          lmocom:license-id-t
          +--ro virtual-account?  string
          +--ro model          lmocom:license-model-t
          +--ro buying-program? identityref
          +--ro offer-type?     identityref
          +--ro external-store? boolean
          +--ro pid            string
          +--ro purchase-order-id? lmocom:purchase-order-t
          +--ro account-id?     string
          +--ro organization-id? string
          +--ro asset?         -> /lmoasset:assets/asset/id
          +--ro feature?       -> /lmousage:features/feature/id
          +--ro state?         lmocom:license-state-t
                    +--ro renewal-profile
                        |---ro purchase-date?     yang:date-and-time
                        |---ro claim-date?        yang:date-and-time
                        |---ro activation-date?   yang:date-and-time
                        |---ro expiration-date?   yang:date-and-time
          +--ro sublicenses
              +--ro sublicense* [id]
                  +--ro id         -> /licenses/license/id

6.1.3. Usage

module: ietf-lmo-usage
  +--ro features
      +--ro feature* [id]
          +--ro id          string
          +--ro name?       string
          +--ro summary?    string
          +--ro category?   string
          +--ro entitlement? string
          +--ro first-available-version? string
          +--ro backported-versions
6.1.4. Incident Management

module: ietf-lmo-incident-management
  +--ro tracking-number
    +--ro tracking-number* [id]
      +--ro id string
      +--ro title? string
      +--ro summary? string
      +--ro severity? string
      +--ro status? string
      +--ro created? yang:date-and-time
      +--ro last_updated? yang:date-and-time
      +--ro capability? string
      +--ro technology? string
      +--ro subtechnology? string
      +--ro problem-type? string
      +--ro resolution? string
      +--ro owner? string
      +--ro support-engineer? string
      +--ro asset? -> /lmoasset:assets/asset/id
      +--ro serial-number? -> /lmoasset:assets/asset/serial-number
      +--ro software-version? -> /lmoasset:assets/asset/software-version
      +--ro feature? -> /lmousage:features/feature/id
      +--ro contract-number? string

6.2. LMO Modules

6.2.1. LMO Common Module

<CODE BEGINS> file "ietf-lmo-common@2021-08-23.yang"
module ietf-lmo-common {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-lmo-common";
  prefix lmocom;
  organization
    "IETF OPSA (Operations and Management Area) Working Group";
  contact
    "WG Web:  <https://datatracker.ietf.org/wg/opsawg/>
    WG List:  <mailto:opsawg@ietf.org>
    Editor:  Marisol Palmero
             <mailto:mpalmero@cisco.com>
    Editor:  Josh Suhr
             <mailto:josuhr@cisco.com>
    Editor:  Sudhendu Kumar
             <mailto:skumar23@ncsu.edu>
  description
    "This YANG module defines a collection of useful data types
     and identity for Lifecycle Management and Operations (LMO)."
typedef license-id-t {
  type string;
  description
    "License ID Type";
}

typedef license-model-t {
  type enumeration {
    enum perpetual {
      description
        "Perpetual license";
    }
    enum subscription {
      description
        "Subscription license";
    }
    enum usage-based {
      description
        "Usage-based license";
    }
    enum other {
      description
        "Undefined license type";
    }
  }
  description
    "Initial revision for Common Module as part of the LMO
    YANG Model";
}

revision 2021-08-23 {
  description
    "Initial revision for Common Module as part of the LMO
    YANG Model";
  reference
    "RFC XXXX: LMO YANG Model";
}
"License Model Type"
}

identity license-buying-program-t {  
    description  
        "License Buying Program that contains the plan to generate revenue for specific asset";
    }

identity enterprise-agreement {  
    base license-buying-program-t;  
    description  
        "Enterprise Agreement";
    }

identity managed-service-license-agreement {  
    base license-buying-program-t;  
    description  
        "Managed Service License Agreement";
    }

identity service-provider-network-agreement {  
    base license-buying-program-t;  
    description  
        "Service Provider Network Agreement";
    }

identity collab-active-user {  
    base license-buying-program-t;  
    description  
        "Collaboration Active User";
    }

identity service-full-coverage {  
    base license-buying-program-t;  
    description  
        "Service Full-Coverage";
    }

identity offer-type-t {  
    description  
        "License Offer Type, part of the plan to generate revenue for specific asset";
    }

identity perpetual-software {  
    base offer-type-t;  
    description  
        "Perpetual software gives the user the right to use the program indefinitely";
    }

identity standalone-hardware {  
    base offer-type-t;  
    description  
        "Standalone hardware is able to function independently of other hardware";
identity on-premise-software-subscription {
  base offer-type-t;
  description
    "On-Premise software subscription, relates to a temporary
    on-prem licencing model, allowing users to pay a per user
    fee";
}

identity cloud-software-saas-subscription {
  base offer-type-t;
  description
    "Cloud Software (SaaS) subscription is a service business
    model where the user is entitled to use the cloud software
    for a specific time period";
}

identity third-party-software {
  base offer-type-t;
  description
    "It includes licenses, agreements, obligations or other
    commitment under which the user can use the asset not
    directly sold by the manufacturer";
}

identity flex-cloud-prem-subscription {
  base offer-type-t;
  description
    "Flex Cloud-Prem subscription allows software vendors to
    limit the number of licenses for the use of the specific
    asset";
}

typedef license-key-t {
  type string;
  description
    "License Key Type";
}

typedef purchase-order-t {
  type string;
  description
    "License purchase order number";
}

typedef license-state-t {
  type enumeration {
    enum inactive {
      description
        "Inactive State";
    } enum active {
      description
        "Active State";
    }
  }
}
enum unknown {
    description
    "Unknown State";
}

description
"License State Type";

typedef asset-id {
    type string;
    description
    "Asset ID Type";
}

typedef vendor-id {
    type enumeration {
        enum cisco {
            description
            "Vendor-id is Cisco";
        }
        enum other {
            description
            "Vendor-id is not determined";
        }
    }
    description
    "Vendor identifier";
}

identity asset-type {
    description
    "type of the asset: hardware, software, software cloud, ...";
}

identity hw {
    base asset-type;
    description
    "Hardware refers to any physical device";
}

identity sw {
    base asset-type;
    description
    "Software refers to a collection of code installed on a
    hardware asset";
}

identity sw-cloud {
    base asset-type;
description
"Cloud-based software, that allows users access to software application that run on a shared computing resources via Internet";
}

identity phone {
base asset-type;
description
"Mobile telephone or a handheld two-way communication device over a cellular network.";
}

identity other {
base asset-type;
description
"Different or additional type not specified as part of another defined asset-type.";
}

identity asset-subtype {
description
"subtype of the asset: router, switch, wireless, controller, ...";
}

identity router {
base asset-subtype;
description
"Network connecting device. It operates at layer-3 of the OSI model.";
}

identity switch {
base asset-subtype;
description
"Network connecting device. It operates at layer-2 (Data Link Layer) of the OSI model.";
}

identity wireless {
base asset-subtype;
description
"Network connecting device. It creates a wireless local area network. It connects to a wired router, switch, or hub via an Ethernet cable, and projects a Wi-Fi signal to a designated area";
}

identity controller {
base asset-subtype;
description
"Centralized device in the network which is used in combination with network connection devices, when there is a need to manage them in large quantities.";
identity board {
    base asset-subtype;
    description
        "Electronic circuit board in an asset which interconnects
         another hardware assets attached to it.";
}

identity p-supply {
    base asset-subtype;
    description
        "Power supply, as it might have independent identity.";
}

identity transceiver {
    base asset-subtype;
    description
        "Device that is both a transmitter and a receiver. Usually
         it's in a single device.
         This is commonly used as a modular network interface";
}

identity others {
    base asset-subtype;
    description
        "Different or additional type not specified as part of another
         defined asset-subtype.";
}

identity version {
    description
        "Base identity for all version types";
}

identity version-sw {
    base version;
    description
        "Version release of the operating system that runs on the
         asset";
}

identity platform-dependency-os {
    description
        "Operating system that creates an environment for the asset
         to get deployed. Enum of options covering OS platform dependency.";
}

identity linux {
    base platform-dependency-os;
    description
        "UNIX like operating system";
}

identity windows {
    base platform-dependency-os;
description
   "Windows operating system";
}
identity macOS {
    base platform-dependency-os;
    description
        "Mac operating system develop by Apple, Inc.";
}
identity darwin {
    base platform-dependency-os;
    description
        "Open-source Unix-like operating system first released by Apple Inc.";
}
identity ubuntu {
    base platform-dependency-os;
    description
        "Linux distribution, used in desktop distribution";
}
identity red-hat {
    base platform-dependency-os;
    description
        "Red Hat Enterprise Linux, released in multiple server and desktop versions";
}
// NEED to extend and include iOS, Android, etc.;

identity role {
    description
        "What the role of a given device/component is in the network. This attribute normally will
        be configured on the specific component during setup. This attribute normally will be
        configured on the specific component during setup";
}
identity border-router {
    base role;
    description
        "Router that provides connectivity between interior and exterior network routers or to the cloud";
}
identity access {
    base role;
    description
        "Router that provides access to a larger communication network of some sort.";
}
identity control-plane {
    base role;
}
description
  "Network component that controls how data packets are
  forwarded";
}
identity edge {
  base role;
  description
  "Router that provides an entry point into enterprise or service
  provider core networks";
}
identity core {
  base role;
  description
  "Component part of the high-speed backbone of the network. It
  provides fast and efficient data transport";
}
identity datacenter {
  base role;
  description
  "Component placed in the data center, maintaining and housing
  back-end IT system and data stores";
}
identity branch {
  base role;
  description
  "Router in a remote branch of an enterprise’s network";
}
identity deployment-mode {
  description
  "This attribute will denote the configured deployment mode
  for the asset and features, if applicable; e.g.,
  High Availability(HA) or Failover cluster, virtual appliance,
  etc.";
}
identity primary {
  base deployment-mode;
  description
  "Asset or features that support critical applications to
  minimize system downtime, to achieve high availability or
  failover";
}
identity secondary {
  base deployment-mode;
  description
  "Redundant asset or feature, that is triggered when the
  primary encounters performance issues, to achieve high
  availability or failover";
identity cloud {
  base deployment-mode;
  description
    "Especially it refers to remote, distributed and shared asset resources (i.e. data storage, computing power, etc.), which are hooked together and meant to operate as a single ecosystem.";
}

identity virtual-appliance {
  base deployment-mode;
  description
    "pre-configured virtual machine image, ready to run on a hypervisor";
}

identity container {
  base deployment-mode;
  description
    "Standard unit of software that packages up code and all its dependencies so the application runs quickly and reliably from one computing environment to another";
}

identity counter-type {
  description
    "Specify the different type of counters, i.e accumulated-count, average-count, last-count, high-water mark count, low-water mark count";
}

identity accumulated {
  base counter-type;
  description
    "monotonically increasing counters. They’re useful for aggregating metric information such as the number of hits on a web page, how many users log into a portal, etc.";
}

identity average {
  base counter-type;
  description
    "typical value in a set of metrics, in particular the mean, which is calculated by dividing the sum of the values in the set by their number.";
}

identity last {
  base counter-type;
  description
    "Last value measured and collected for specific metric.";
}
identity high-water-mark {
    base counter-type;
    description
    "Highest level of value in a set of metrics."
}

identity low-water-mark {
    base counter-type;
    description
    "Lowest level of value in a set of metrics."
}

identity feature-scope {
    description
    "Optional tag that could apply to any usage feature, so that
    if there are multiple dimensions of reporting that need to
    be accommodated (i.e., report feature usage by 'site')"
}

identity site {
    base feature-scope;
    description
    "Single location, part of the network"
}

identity network {
    base feature-scope;
    description
    "Scope limited to the networking assets"
}

typedef feature-usage-type {
    type enumeration {
        enum none {
            description
            "No Usage"
        }
        enum low {
            description
            "Usage meeting the Low Threshold"
        }
        enum medium {
            description
            "Usage meeting the Medium Threshold"
        }
        enum high {
            description
            "Usage meeting the High Threshold"
        }
        // NEED to elaborate more on this list, based on use case
        // validation
    }
    description
}
"feature usage % 0-25-50-75-100;"
}
}
<CODE ENDS>

6.2.2. Aggregated Asset Inventory

<CODE BEGINS> file "ietf-lmo-assets-inventory@2021-10-25.yang"
module ietf-lmo-assets-inventory {
    yang-version 1.1;
    namespace "urn:ietf:params:xml:ns:yang:ietf-lmo-assets-inventory";
    prefix lmo-asset;
    import ietf-yang-types {
        prefix yang;
    }
    import ietf-lmo-common {
        prefix lmocom;
    }
    import ietf-geo-location {
        prefix geo;
        revision-date 2019-02-17;
    }
    import ietf-inet-types {
        prefix inet;
    }

    organization
    "IETF OPSA (Operations and Management Area) Working Group";
    contact
    "WG Web: <https://datatracker.ietf.org/wg/opsawg/>
    WG List: <mailto:opsawg@ietf.org>
    Editor: Marisol Palmero
        <mailto:mpalmero@cisco.com>
    Editor: Josh Suhr
        <mailto:josuhr@cisco.com>
    Editor: Sudhendu Kumar
        <mailto:skumar23@ncsu.edu>"
    description
    "This YANG module includes the concept asset aggregation
and platform dependency of an asset.

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authors of the code. All rights reserved.

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forth in Section 4.c of the IETF Trust’s Legal Provisions
Relating to IETF Documents

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 2021-10-25 {
  description
    "Initial revision for Aggregated Assets Inventory as part of
    the LMO YANG Model";
  reference
    "RFC XXXX: LMO YANG Model";
}

container capture-info {
  config false;
  description
    "Capture information for this data";
  leaf collected-on {
    type yang:date-and-time;
    description
      "Time at which this data was collected";
  }
  leaf collected-from {
    type string;
    description
      "Identifier for original source of this data";
  }
}

container assets {
  config false;
  description
    "Assets container includes attributes that add the aggregated
    view";
  list asset {
    key "id";
    description
      "Asset ID";
    leaf id {
      type lmocom:asset-id;
      description
        "Unique identifier for the hardware or software instance.
        It could be same as the Serial Number.";
    }
    leaf vendor {
      type lmocom:vendor-id;
      description
        "Vendor or Manufacturer name or identifier; e.g. Cisco";
    }
  }
}
leaf pid {
  type string;
  description
    "Part or Product Identifier";
}
leaf serial-number {
  type string;
  description
    "Serial number";
}
leaf vid {
  type string;
  description
    "Hardware Version ID";
}
leaf mac-address {
  type yang:mac-address;
  description
    "The mac-address type represents an IEEE 802 MAC address. The canonical representation uses lowercase characters.";
}
leaf-list ip-address {
  type inet:ip-address;
  description
    "IP address, representing the management IP of the asset. It can refer to ipv4 and/or ipv6 address.";
}
leaf entity-name {
  type string;
  description
    "Hardware type, e.g., chassis, slot, or power-supply";
}
leaf product-description {
  type string;
  description
    "Standard description of the asset; e.g., '1-port Gigabit Ethernet'";
}
leaf udi {
  type string;
  description
    "Identify uniquely an asset = vendor-id + pid + id";
}
leaf transparency-info {
  type inet:uri;
  description
    "Link to software bill of material and security advisory information, see draft-ietf-opsawg-sbom-access";
leaf type {
  type identityref {
    base lmocom:asset-type;
  }
  description
    "Asset type; e.g. hardware, software, sw-cloud, ...
    It can be extended";
}
leaf subtype {
  type identityref {
    base lmocom:asset-subtype;
  }
  description
    "Subtype of hardware or software; e.g. router, switch,
    wireless, controller, ...";
}
leaf role {
  type identityref {
    base lmocom:role;
  }
  description
    "What the role of a given device/component is in the
    network. This attribute normally will be configured on the
    specific component during setup";
}
leaf aggregation {
  type boolean;
  must ".../number-of-instances = 1 or . = 'true'";
  default false;
  description
    "Asset aggregation; e.g., false (default) or true";
}
leaf number-of-instances {
  type uint32;
  description
    "Number of instances or endpoints covered by the aggregated
    asset. If different from 1, it should enforce that
    aggregation attribute is set to true";
}
leaf platform-dependency-os {
  type identityref {
    base lmocom:platform-dependency-os;
  }
  description
    "Operating system for the asset to be deployed.";
}
container install-location {

uses geo:geo-location;
    description
        "Physical installed location of the product. Location is
        provided based on what customer/user configures";
}
leaf deployment-mode {
    type identityref {
        base lmocom:deployment-mode;
    }
    description
        "Deployment mode for the asset, if applicable; e.g.,
        HA cluster, virtual appliance, etc.";
}
leaf activation-date {
    type yang:date-and-time;
    description
        "Date of asset activation or initial contact";
}
leaf software-version {
    type string;
    description
        "Software version running on the hardware device or
        software component";
}
container hotfixes {
    config false;
    description "list of hotfixes";
    list hostfix {
        description
            "List of hotfixes that have been installed";
        leaf version {
            type identityref {
                base lmocom:version;
            }
            description
                "It includes the first hotfix installed";
        }
        leaf order {
            type uint8;
            description
                "It refers to the order of how the hotfixes have been
                installed, range 0..100";
        }
    }
    leaf software-type {
        type string;
        description
"Software type or Operating System";
}
leaf sign-of-life-timestamp {
  type yang:date-and-time;
  description
    "Date of last contact";
}
leaf tags {
  type string;
  description
    "Comma-separated descriptive tags for this asset";
}
}
} container subassets {
  config false;
  description
    "Subassets container, includes assets under parent assets";
list subasset {
  key "id";
  description
    "Subasset ID";
  leaf id {
    type leafref {
      path "/assets/asset/id";
    }
    description
      "Reference to Asset-ID";
  }
}
}

6.2.3. Licenses

<CODE BEGINS> file "ietf-lmo-licenses@2021-10-25.yang"
module ietf-lmo-licenses {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-lmo-licenses";
  prefix lmolicense;
  import ietf-yang-types {
    prefix yang;
  }
  import ietf-lmo-common {
    prefix lmocom;
  }
  import ietf-lmo-assets-inventory {

Palmero, et al. Expires 29 April 2022
prefix lmoasset;
}
import ietf-lmo-usage {
  prefix lmousage;
}

organization
  "IETF OPSA (Operations and Management Area) Working Group";
contact
  "WG Web:  <https://datatracker.ietf.org/wg/opsawg/>
  WG List:  <mailto:opsawg@ietf.org>
  Editor:  Marisol Palmero  
            <mailto:mpalmero@cisco.com>
  Editor:  Josh Suhr  
            <mailto:josuhr@cisco.com>
  Editor:  Sudhendu Kumar  
            <mailto:skumar23@ncsu.edu>";

description
  "This YANG module includes the licenses attributes of a product.

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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 2021-10-25 {
  description
    "Initial revision for Licenses Module as part of the LMO YANG Model";
  reference
    "RFC XXXX: LMO YANG Model";
}

container capture-info {
  config false;
  description
    "Capture information for this data";
  leaf collected-on {
    type yang:date-and-time;
    description

"Time at which this data was collected";
}
leaf collected-from {
  type string;
  description
    "Identifier for original source of this data";
}

// Can we capture licensing ties to API access where we may be
// licensed on events queries per second, minute, hour, etc.
// This is a popular model in the cloud space for example the Google
// MAPs API??

container licenses {
  config false;
  description
    "Licenses";
  list license {
    key "id";
    description
      "License ID";
    leaf id {
      type lmocom:license-id-t;
      description
        "Universal identifier for a license or bundle of licenses";
    }
    leaf virtual-account {
      type string;
      description
        "Virtual Accounts help to organize assets in a way that is
        logical for the business. The most common use of a Virtual
        Account is to provide access and allocate specific
        licenses to different departments or geographies while
        maintaining an overall view of the organizational usage";
    }
    leaf model {
      type lmocom:license-model-t;
      mandatory true;
      description
        "License Model or Type";
    }
    leaf buying-program {
      type identityref {
        base lmocom:license-buying-program-t;
      }
      description
        "License buying program, if applicable";
    }
}
leaf offer-type {
  type identityref {
    base lmocom:offer-type-t;
  }
  description
    "License offer type, if applicable";
}

leaf external-store {
  type boolean;
  default false;
  description
    "Licensing goes through an external store";
}

leaf pid {
  type string;
  mandatory true;
  description
    "License Product Identifier";
}

leaf purchase-order-id {
  type lmocom:purchase-order-t;
  description
    "License Order Number";
}

leaf account-id {
  type string;
  description
    "Account identifier entitled to the license. Account-id
    could e.g., be composed by account or customer name +
    organization identifier";
}

leaf organization-id {
  type string;
  description
    "Organization Domain Name";
}

leaf asset {
  type leafref {
    path "/lmoasset:assets/lmoasset:asset/lmoasset:id";
  }
  description
    "Asset to which this license is attached";
}

leaf feature {
  type leafref {
    path "/lmousage:features/lmousage:feature/lmousage:id";
  }
description
"feature to which this license is attached";
}
leaf state {
  type lmocom:license-state-t;
  description
  "License state; e.g., active, inactive, or unknown";
}
container renewal-profile {
  description
  "Profile of license renewal status and information";
  leaf purchase-date {
    type yang:date-and-time;
    description
    "Purchase Date";
  }
  leaf claim-date {
    type yang:date-and-time;
    description
    "Claim Date - if different from Purchase Date";
  }
  leaf activation-date {
    type yang:date-and-time;
    description
    "Activation Date";
  }
  leaf expiration-date {
    type yang:date-and-time;
    description
    "Expiration Date";
  }
}
container sublicenses {
  description
  "Sublicenses";
  list sublicense {
    key "id";
    description
    "Sublicenses";
    leaf id {
      type leafref {
        path "/licenses/license/id";
      }
      description
      "Universal license identifier";
    }
  }
}
6.2.4. Usage

<CODE BEGINS> file "ietf-lmo-usage@2021-10-25.yang"
module ietf-lmo-usage {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-lmo-usage";
  prefix lmousage;
  import ietf-yang-types {
    prefix yang;
  }
  import ietf-lmo-assets-inventory {
    prefix lmoasset;
  }
  import ietf-lmo-common {
    prefix lmocom;
  }
  organization "IETF OPSA (Operations and Management Area) Working Group";
  contact "WG Web: <https://datatracker.ietf.org/wg/opsawg/>  
  WG List: <mailto:opsawg@ietf.org>  
  Editor: Marisol Palmero <mailto:mpalmero@cisco.com>  
  Editor: Josh Suhr <mailto:josuhr@cisco.com>  
  Editor: Sudhendu Kumar <mailto:skumar23@ncsu.edu>>;
  description "This YANG module includes the different attributes that define 
  description, usage and resource consumption for specific 
  features or capabilities of assets."

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  forth in Section 4.c of the IETF Trust’s Legal Provisions 
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Palmero, et al. Expires 29 April 2022 [Page 37]
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 2021-10-25 {
  description
    "Initial revision for Product Usage Module as part of the LMO YANG Model";
  reference
    "RFC XXXX: LMO YANG Model";
}

container features {
  config false;
  description
    "Features";
  list feature {
    key "id";
    description
      "Feature List";
    leaf id {
      type string;
      description
        "Identifies feature uniquely across all products of a particular vendor: vendor-id/asset-id/id";
    }
    leaf name {
      type string;
      description
        "Friendly name of the feature";
    }
    leaf summary {
      type string;
      description
        "Brief description of the feature";
    }
    leaf category {
      type string;
      description
        "Feature category or tag list (as applicable to the product)";
    }
    leaf entitlement {
      type string;
      description
        "Minimum entitlement level, subscription, or license level required for the feature";
    }
    leaf first-available-version {
      type string;
description
    "The first version in which this feature was enabled";
}
container backported-versions {
    config false;
    description
        "software patch or update is taken from a recent software
        version and applied to an older version of the same
        software";
    list backported-version {
        config false;
        description
            "Backport releases to older release";
        leaf version {
            type identityref {
                base lmocom:version;
            }
            description
                "version of the backport release";
        }
    }
}
leaf scope {
    type identityref {
        base lmocom:feature-scope;
    }
    description
        "Optional tag that could apply to any of the usage
        features, so that if there are multiple dimensions of
        reporting that need to be accommodated (i.e., report
        feature usage by 'site')";
}
list config-options {
    key "id";
    description
        "Feature configuration profile - optional, for features
        that require configuration beyond enable/disable";
    leaf id {
        type string;
        description
            "Identify feature configuration option uniquely across
            all products";
    }
    leaf name {
        type string;
        description
            "Friendly name of the feature option";
    }
}
leaf summary {
    type string;
    description
        "Brief description of the feature option";
}
list characteristic {
    key "id";
    description
        "Characteristics of feature configuration options,
        i.e. value=enabled/disabled";
    leaf id {
        type string;
        description
            "Identifier for feature option configuration
             characteristic";
    }
    leaf name {
        type string;
        description
            "Friendly name for feature option configuration
             characteristic";
    }
    leaf value {
        type string;
        description
            "Configuration characteristic value; describes how 
            this feature option characteristic is configured";
    }
}
leaf asset {
    type leafref {
        path "/lmoasset:assets/lmoasset:asset/lmoasset:id";
    }
    description
        "Asset to which this feature is attached";
}
description
  "Reference to Feature ID";
}
}
}
}
container usages {
  config false;
  description
    "feature usage characteristic";
  list usage {
    key "id";
    description
      "Feature usage profile";
    leaf id {
      type string;
      description
        "Identify feature usage characteristic uniquely across all products";
    }
    leaf feature {
      type leafref {
        path "/features/feature/id";
      }
      description
        "usage link to a feature";
    }
  }
  container capture-info {
    config false;
    description
      "Capture information for this data";
    leaf collected-on {
      type yang:date-and-time;
      description
        "Time at which this data was collected";
    }
    leaf collected-from {
      type string;
      description
        "Identifier for original source of this data";
    }
  }
  leaf name {
    type string;
    description
      "Name of feature usage characteristic";
  }
}
leaf summary {
  type string;
  description
    "Brief description of feature usage characteristic";
}
leaf uri {
  type string;
  description
    "Target URI of feature characteristic, if applicable - e.g.,
      for clickstream or API";
}
leaf deployment-mode {
  type identityref {
    base lmocom:deployment-mode;
  }
  description
    "Deployment mode for the feature. When applicable, feature
      might be independent of the deployment mode in the asset;
      e.g., cloud, HA cluster, virtual appliance, etc.";
}
leaf scope {
  type identityref {
    base lmocom:feature-scope;
  }
  description
    "Optional tag that could apply to any of the usage
      features, so that if there are multiple dimensions of
      reporting that need to be accommodated, (i.e., report
      feature usage by 'site')";
}
leaf activation-status {
  type string;
  description
    "Feature activation status for this instance of the
      product (on/off; active/inactive; enabled/disabled)";
}
leaf instances {
  type uint32;
  description
    "Number of instances or end-points using this feature";
}
leaf count-type {
  type identityref {
    base lmocom:counter-type;
  }
  description
    "Specify the counter type i.e accumulated-count,
average-count, last-count, high-water mark count
   (+time stamp), low-water mark count (+time stamp)";
} leaf timestamp {
   type yang:date-and-time;
   description
      "Some counters will benefit from timestamp based on the
      time when the counter has been collected";
} leaf count {
   type uint32;
   units "times";
   description
      "Count of times the feature has been used";
} list frequency {
   key "name";
   description
      "Frequency with which the feature is used";
   leaf name {
      type string {
         length "1..64";
      } description
         "reference in case that feature is for different
         purpose of usage";
   } leaf type-freq {
      type string;
      description
         "Frequency type, i.e daily, weekly, monthly";
   } leaf value {
      type yang:counter64;
      description
         "Value collected for the usage";
   } list resource-consumption {
   key "id";
   description
      "Resource consumption profile";
   leaf id {
      type string;
      description
         "Identify resource for consumption measurement";
   } leaf name {

type string;
    description
        "Friendly name of the resource";
}
leaf summary {
    type string;
    description
        "Brief description of the resource";
}
list characteristic {
    key "id";
    description
        "Characteristic of resource consumption";
    leaf id {
        type string;
        description
            "Identifier for resource consumption characteristic";
    }
    leaf name {
        type string;
        description
            "Friendly name for resource consumption characteristic";
    }
    leaf unit {
        type string;
        description
            "Unit of measurement for the characteristic";
    }
    // NEED to define identity type for unit: min, hour, sec,
    // days, ...
    leaf value {
        type yang:counter64;
        description
            "Resource consumption characteristic measurement";
    }
    leaf value-max {
        type yang:counter64;
        description
            "Maximum resource consumption characteristic value";
    }
}
6.2.5. Incident Management

This YANG module includes the incident management attributes to handle incidents.

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for full legal notices.
revision 2021-10-25 {
  description
    "Initial revision for Incident Management as part of
    the LMO YANG Model";
  reference
    "RFC XXXX: LMO YANG Model";
}

container tracking-number {
  config false;
  description
    "Incident Tracking Incident Management Case Number";
list tracking-number {
  key "id";
  description
    "Incident Tracking Incident Management Case Number List,
    internal to Developer, ie. INCxxxxx";
  leaf id {
    type string;
    description
      "Technical Support Center Case Number id";
  }
  leaf title {
    type string;
    description
      "headline Incident Case";
  }
  leaf summary {
    type string;
    description
      "Problem description summary";
  }
  leaf severity {
    type string;
    description
      "severity, in some cases also defined as priority";
    // NEED to define different levels of severity, from
    // severity 1 to 6, i.e. Sev1: network down, Sev6: enhancement
  }
  leaf status {
    type string;
    description
      "case status, i.e. Customer-Pending, Customer
      Engineer-Pending, Developer-Pending, Closed, Open, etc.";
    // NEED to define different status
  }
  leaf created {

type yang:date-and-time;
description
"created date-and-time";
}
leaf last_updated {
  type yang:date-and-time;
  description
  "last updated date-and-time";
}
leaf capability {
  type string;
  description
  "i.e. to reveal associated RMA items";
}
leaf technology{
  type string;
  description
  "Technology related";
}
leaf subtechnology{
  type string;
  description
  "Subtechnology related";
}
leaf problem-type{
  type string;
  description
  "Problem type definition, i.e. network, faulty hardware,
  performance, security, etc.";
}
leaf resolution{
  type string;
  description
  "code (closed cases only)";
}
leaf owner{
  type string;
  description
  "Customer in charge of the case";
  // NEED to add contact information: email and phone number
}
leaf support-engineer{
  type string;
  description
  "Customer Support Engineer in charge of the case";
  // NEED to add contact information: email and phone number
}
leaf asset {
type leafref {
    path "/lmoasset:assets/lmoasset:asset/lmoasset:id";
}
description
"Asset to which this incident is attached";
}
leaf serial-number {
    type leafref {
        path "/lmoasset:assets/lmoasset:asset/lmoasset:serial-number";
    }
description
"Serial-number to which this incident is attached";
}
leaf software-version {
    type leafref {
        path "/lmoasset:assets/lmoasset:asset/lmoasset:software-version";
    }
description
"Software version running in the asset to which this incident case is attached";
}
leaf feature {
    type leafref {
        path "/lmousage:features/lmousage:feature/lmousage:id";
    }
description
"Asset to which this incident is attached";
}
leaf contract-number {
    type string;
description
"Support contract number";
// NEED to evaluate if it should be independent container. It should be associated to asset and license
}

<CODE ENDS>

7. Deployment Considerations

LMO Data Models defines the data schemas for LMO data. LMO Data Models are based on YANG. YANG data models can be used independent of the transport and can be converted into any encoding format supported by the network configuration protocol. YANG is a protocol independent.
To enable the exchange of LMO data among all interested parties, deployment considerations that are out of the scope of this document, will need to include:

* The data structure to describe all metrics and quantify relevant data consistently, i.e. specific formats like XML or JSON encoded message would be deemed valid or invalid based on LMO models.

* The process to share and collect LMO data across the consumers consistently, including the transport mechanism. The LMO YANG models can be used with network management protocols such as NETCONF [RFC6241], RESTCONF [RFC8040], streaming telemetry, etc. OpenAPI specification might also help to consume LMO metrics.

* How the configuration of assets should be done.

8. Security Considerations

The security considerations mentioned in section 17 of [RFC7950] apply.

LMO brings several security and privacy implications because of the various components and attributes of the information model. For example, each functional component can be tampered with to give manipulated data. LMO when used alone or with other relevant data, can identify an individual, revealing Personal Identifiable Information (PII). Misconfigurations can lead to data being accessed by unauthorized entities.

Methods exist to secure the communication of management information. The transport entity of the functional model MUST implement methods for secure transport. This document also contains an Information model and Data-Model in which none of the objects defined are writable. If the objects are deemed sensitive in a particular environment, access to them MUST be restricted using appropriately configured security and access control rights. The information model contains several optional elements which can be enabled or disabled for the sake of privacy and security. Proper authentication and audit trail MUST be included for all the users/processes that access the LMO.

9. IANA Considerations

9.1. The IETF XML Registry

This document registers URIs in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the registrations defined below are requested:
9.2. The YANG Module Names Registry

This document registers YANG modules in the YANG Module Names registry [RFC7950]. Following the format in [RFC7950], the registrations defined below are requested:

name: ietf-lmo-common
maintained by IANA: N
prefix: lmocom
reference: RFC XXXX

name: ietf-lmo-asset-inventory
maintained by IANA: N
prefix: lmoasset
reference: RFC XXXX

name: ietf-lmo-licenses
maintained by IANA: N
prefix: lmolicense
reference: RFC XXXX
name: ietf-lmo-product-usage
maintained by IANA: N
prefix: lmousage
reference: RFC XXXX

name: ietf-lmo-incident-management
maintained by IANA: N
prefix: lmoscm
reference: RFC XXXX

10. References

10.1. Normative References


10.2. Informative References


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Change log

RFC Editor Note: This section is to be removed during the final publication of the document.

version 02
* "Support case" renamed to "incident".
* Add MAC address and IP address attributes under asset-inventory YANG module.
* Link among objects & YANG modules (notably with feature).
* New text about asset usage.

version 01
* Fixes for YANG validator and idnits warnings.

version 00
* Initial version.

Authors’ Addresses

Marisol Palmero
Cisco Systems
Email: mpalmero@cisco.com

Frank Brockners
Cisco Systems
Email: fbrockne@cisco.com

Sudhendu Kumar
NC State University
Email: skumar23@ncsu.edu

Shwetha Bhandari
Thoughtspot
Email: shwetha.bhandari@thoughtspot.com

Camilo Cardona
NTT
Email: camilo@ntt.net
Abstract

This document describes a format to record captured packets to a file. This format is extensible; Wireshark can currently read and write it, and libpcap can currently read some pcapng files.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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This Internet-Draft will expire on 7 April 2022.

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1. Introduction

The problem of exchanging packet traces becomes more and more critical every day; unfortunately, no standard solutions exist for this task right now. One of the most accepted packet interchange formats is the one defined by libpcap, which is rather old and is lacking in functionality for more modern applications particularly from the extensibility point of view.

This document proposes a new format for recording packet traces. The following goals are being pursued:

Extensibility: It should be possible to add new standard capabilities to the file format over time, and third parties should be able to enrich the information embedded in the file with proprietary extensions, with tools unaware of newer extensions being able to ignore them.

Portability: A capture trace must contain all the information needed to read data independently from network, hardware and operating system of the machine that made the capture.

Merge/Append data: It should be possible to add data at the end of a given file, and the resulting file must still be readable.

2. 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.

2.1. Acronyms

The following acronyms are used throughout this document:

SHB: Section Header Block
IDB: Interface Description Block
ISB: Interface Statistics Block
3.  General File Structure

3.1.  General Block Structure

A capture file is organized in blocks, that are appended one to another to form the file. All the blocks share a common format, which is shown in Figure 1.

```
+---------------------------------------------+
|                          Block Type           |
+---------------------------------------------+
|                      Block Total Length      |
+---------------------------------------------+
|                          Block Body          |
+---------------------------------------------+
|                      Block Total Length      |
+---------------------------------------------+
```

Figure 1: Basic block structure.

The fields have the following meaning:

* **Block Type (32 bits):** a unique unsigned value that identifies the block. Values whose Most Significant Bit (MSB) is equal to 1 are reserved for local use. They can be used to make extensions to the file format to save private data to the file. The list of currently defined types can be found in Section 10.1.

* **Block Total Length (32 bits):** an unsigned value giving the total size of this block, in octets. For instance, the length of a block that does not have a body is 12 octets: 4 octets for the Block Type, 4 octets for the initial Block Total Length and 4 octets for the trailing Block Total Length. This value MUST be a multiple of 4.

* **Block Body:** content of the block.
* Block Total Length: total size of this block, in octets. This field is duplicated to permit backward file navigation.

This structure, shared among all blocks, makes it easy to process a file and to skip unneeded or unknown blocks. Some blocks can contain other blocks inside (nested blocks). Some of the blocks are mandatory, i.e. a capture file is not valid if they are not present, other are optional.

The General Block Structure allows defining other blocks if needed. A parser that does not understand them can simply ignore their content.

3.2. Block Types

The currently standardized Block Type codes are specified in Section 10.1; they have been grouped in the following four categories:

The following MANDATORY block MUST appear at least once in each file:

* Section Header Block (Section 4.1): it defines the most important characteristics of the capture file.

The following OPTIONAL blocks MAY appear in a file:

* Interface Description Block (Section 4.2): it defines the most important characteristics of the interface(s) used for capturing traffic. This block is required in certain cases, as described later.

* Enhanced Packet Block (Section 4.3): it contains a single captured packet, or a portion of it. It represents an evolution of the original, now obsolete, Packet Block (Appendix A). If this appears in a file, an Interface Description Block is also required, before this block.

* Simple Packet Block (Section 4.4): it contains a single captured packet, or a portion of it, with only a minimal set of information about it. If this appears in a file, an Interface Description Block is also required, before this block.

* Name Resolution Block (Section 4.5): it defines the mapping from numeric addresses present in the packet capture and the canonical name counterpart.
* Interface Statistics Block (Section 4.6): it defines how to store some statistical data (e.g. packet dropped, etc) which can be useful to understand the conditions in which the capture has been made. If this appears in a file, an Interface Description Block is also required, before this block.

* Custom Block (Section 4.8): it contains vendor-specific data in a portable fashion.

The following OBSOLETE block SHOULD NOT appear in newly written files (but is documented in the Appendix for reference):

* Packet Block (Appendix A): it contains a single captured packet, or a portion of it. It is OBSOLETE, and superseded by the Enhanced Packet Block (Section 4.3).

The following EXPERIMENTAL blocks are considered interesting but the authors believe that they deserve more in-depth discussion before being defined:

* Alternative Packet Blocks
* Compression Block
* Encryption Block
* Fixed Length Block
* Directory Block
* Traffic Statistics and Monitoring Blocks
* Event/Security Blocks

Requests for new standardized Block Type codes should be made by creating a pull request to update this document as described in Section 10.1.

3.3. Logical Block Hierarchy

The blocks build a logical hierarchy as they refer to each other. Figure 2 shows the logical hierarchy of the currently defined blocks in the form of a "tree view":

---

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Section Header

+- Interface Description
  +- Simple Packet
  +- Enhanced Packet
  +- Interface Statistics
+- Name Resolution

Figure 2: Logical Block Hierarchy of a pcapng File

For example: each captured packet refers to a specific capture interface, the interface itself refers to a specific section.

3.4. Physical File Layout

The file MUST begin with a Section Header Block. However, more than one Section Header Block can be present in the capture file, each one covering the data following it until the next one (or the end of file). A Section includes the data delimited by two Section Header Blocks (or by a Section Header Block and the end of the file), including the first Section Header Block.

In case an application cannot read a Section because of different version number, it MUST skip everything until the next Section Header Block. Note that, in order to properly skip the blocks until the next section, all blocks MUST have the fields Type and Length at the beginning. In order to properly skip blocks in the backward direction, all blocks MUST have the Length repeated at the end of the block. These are mandatory requirements that MUST be maintained in future versions of the block format.

Figure 3 shows a typical file layout, with a single Section Header that covers the whole file.

+-----------------------------------------------+-----------------------------------------------+
| SHB v1.0                                     | Data                                         |
+-----------------------------------------------+-----------------------------------------------+

Figure 3: File structure example: Typical layout with a single Section Header Block

Figure 4 shows a file that contains three headers, and is normally the result of file concatenation. An application that understands only version 1.0 of the file format skips the intermediate section and restart processing the packets after the third Section Header.
Figure 4: File structure example: three Section Header Blocks in a single file

Figure 5 shows a file comparable to a "classic libpcap" file - the minimum for a useful capture file. It contains a single Section Header Block (SHB), a single Interface Description Block (IDB) and a few Enhanced Packet Blocks (EPB).

Figure 5: File structure example: a pcapng file similar to a classical libpcap file

Figure 6 shows a complex example file. In addition to the minimum file above, it contains packets captured from three interfaces, capturing on the third of which begins after packets have arrived on other interfaces, and also includes some Name Resolution Blocks (NRB) and an Interface Statistics Block (ISB).

Figure 6: File structure example: complex pcapng file

The last example should make it obvious that the block structure makes the file format very flexible compared to the classical libpcap format.

3.5. Options

All the block bodies MAY embed optional fields. Optional fields can be used to insert some information that may be useful when reading data, but that is not really needed for packet processing. Therefore, each tool can either read the content of the optional fields (if any), or skip some of them or even all at once.

A block that may contain options must be structured so that the number of octets of data in the Block Body that precede the options can be determined from that data; that allows the beginning of the...
options to be found. That is true for all standard blocks that support options; for Custom Blocks that support options, the Custom Data must be structured in such a fashion. This means that the Block Length field (present in the General Block Structure, see Section 3.1) can be used to determine how many octets of optional fields, if any, are present in the block. That number can be used to determine whether the block has optional fields (if it is zero, there are no optional fields), to check, when processing optional fields, whether any optional fields remain, and to skip all the optional fields at once.

Options are a list of Type - Length - Value fields, each one containing a single value:

* Option Type (16 bits): an unsigned value that contains the code that specifies the type of the current TLV record. Option types whose Most Significant Bit is equal to one are reserved for local use; therefore, there is no guarantee that the code used is unique among all capture files (generated by other applications), and is most certainly not portable. For cross-platform globally unique vendor-specific extensions, the Custom Option MUST be used instead, as defined in Section 3.5.1).

* Option Length (16 bits): an unsigned value that contains the actual length of the following 'Option Value' field without the padding octets.

* Option Value (variable length): the value of the given option, padded to a 32-bit boundary. The actual length of this field (i.e. without the padding octets) is specified by the Option Length field.

Requests for new standardized option codes for a given block should be made by creating a pull request to update this document as described in Section 10.1.
A given option may have a fixed length, in which case all instances of that option have a length that is equal to the specified fixed length, or a variable length, in which case the option has a minimum length and all instances of that option must have a length equal to or greater than the specified minimum length. The length of fixed-length options, and the minimum length of variable-length options, is specified in the description of the option; if the minimum length of a variable-length option is not specified, a zero-length option is valid. Software that reads these files SHOULD report options that have an invalid length as errors; the software MAY stop processing the file if it sees an option that has invalid length, or MAY ignore the option and continue processing it. Software that writes these files MUST NOT write files with options that have invalid lengths.

If an option’s value is a string, the value is not necessarily zero-terminated. Software that reads these files MUST NOT assume that strings are zero-terminated, and MUST treat a zero-value octet as a string terminator.

Some options may be repeated several times; for example, a block can have multiple comments, and an Interface Description Block can give multiple IPv4 or IPv6 addresses for the interface if it has multiple IPv4 or IPv6 addresses assigned to it. Other options may appear at most once in a given block.

The option list is terminated by an option which uses the special ‘End of Option’ code (opt_endofopt). Code that writes pcapng files MUST put an opt_endofopt option at the end of an option list. Code that reads pcapng files MUST NOT assume an option list will have an opt_endofopt option at the end; it MUST also check for the end of the block, and SHOULD treat blocks where the option list has no opt_endofopt option as if the option list had an opt_endofopt option at the end.

The format of the optional fields is shown in Figure 7.
The following codes can always be present in any optional field:

<table>
<thead>
<tr>
<th>Name</th>
<th>Code</th>
<th>Length</th>
<th>Multiple allowed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>opt_endofopt</td>
<td>0</td>
<td>0</td>
<td>no</td>
</tr>
<tr>
<td>opt_comment</td>
<td>1</td>
<td>variable</td>
<td>yes</td>
</tr>
<tr>
<td>opt_custom</td>
<td>2988/2989/19372/19373</td>
<td>variable</td>
<td>yes</td>
</tr>
</tbody>
</table>

Table 1: Common Options

opt_endofopt:
The opt_endofopt option delimits the end of the optional fields. This option MUST NOT be repeated within a given list of options.

opt_comment:
The opt_comment option is a UTF-8 string containing human-readable comment text that is associated to the current block. Line separators SHOULD be a carriage-return + linefeed (‘\r\n’) or just linefeed (‘\n’); either form may appear and be considered a line separator. The string is not zero-terminated.
Examples: "This packet is the beginning of all of our problems",
"Packets 17-23 showing a bogus TCP retransmission!\r\nThis is reported in bugzilla entry 1486.\nIt will be fixed in the future."

**opt_custom:**
This option is described in detail in Section 3.5.1.

### 3.5.1. Custom Options

Custom Options are used for portable, vendor-specific data related to the block they’re in. A Custom Option can be in any block type that can have options, can be repeated any number of times in a block, and may come before or after other option types - except the `opt_endofopt` option, which is always the last option. Different Custom Options, of different type codes and/or different Private Enterprise Numbers, may be used in the same pcapng file. See Section 5 for additional details.

```
1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Custom Option Code        |         Option Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Private Enterprise Number (PEN)                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Custom Data                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

*Figure 8: Custom Options Format*

The Custom Option has the following fields:

* Custom Option Code: The code number for the Custom Option, which can be one of the following decimal numbers:

2988:
This option code identifies a Custom Option containing a UTF-8 string in the Custom Data portion. The string is not zero-terminated. This Custom Option can be safely copied to a new file if the pcapng file is manipulated by an application; otherwise 19372 should be used instead. See Section 5.2 for details.

2989:
This option code identifies a Custom Option containing binary octets in the Custom Data portion. This Custom Option can be safely copied to a new file if the pcapng file is manipulated by an application; otherwise 19372 should be used instead. See Section 5.2 for details.

19372:
This option code identifies a Custom Option containing a UTF-8 string in the Custom Data portion. The string is not zero-terminated. This Custom Option should not be copied to a new file if the pcapng file is manipulated by an application. See Section 5.2 for details.

19373:
This option code identifies a Custom Option containing binary octets in the Custom Data portion. This Custom Option should not be copied to a new file if the pcapng file is manipulated by an application. See Section 5.2 for details.

* Option Length: as described in Section 3.1, this contains the length of the option’s value, which includes the 4-octet Private Enterprise Number and variable-length Custom Data fields, without the padding octets.

* Private Enterprise Number: An IANA-assigned Private Enterprise Number identifying the organization which defined the Custom Option. See Section 5.1 for details. The PEN MUST be encoded using the same endianness as the Section Header Block it is within the scope of.

* Custom Data: the custom data, padded to a 32 bit boundary.

3.6. Data format

3.6.1. Endianness

Data contained in each section will always be saved according to the characteristics (little endian / big endian) of the capturing machine. This refers to all the fields that are saved as numbers and that span over two or more octets.

The approach of having each section saved in the native format of the generating host is more efficient because it avoids translation of data when reading / writing on the host itself, which is the most common case when generating/processing capture captures.
Please note: The endianness is indicated by the Section Header Block (Section 4.1). Since this block can appear several times in a pcapng file, a single file can contain both endianness variants.

3.6.2. Alignment

All fields of this specification use proper alignment for 16- and 32-bit values. This makes it easier and faster to read/write file contents if using techniques like memory mapped files.

The alignment octets (marked in this document e.g. with "padded to 32 bits") MUST be filled with zeroes.

Please note: 64-bit values are not aligned to 64-bit boundaries. This is because the file is naturally aligned to 32-bit boundaries only. Special care MUST be taken when reading and writing such values. (Note also that some 64-bit values are represented as a 64-bit integer in the endianness of the machine that wrote the file, and others are represented as 2 32-bit values, one containing the upper 32 bits of the value and one containing the lower 32 bits of the value, each written as 32-bit integers in the endianness of the machine that wrote the file. Neither of these formats guarantee 64-bit alignment.)

4. Block Definition

This section details the format of the blocks currently defined.

4.1. Section Header Block

The Section Header Block (SHB) is mandatory. It identifies the beginning of a section of the capture file. The Section Header Block does not contain data but it rather identifies a list of blocks (interfaces, packets) that are logically correlated. Its format is shown in Figure 9.
The meaning of the fields is:

* **Block Type:** The block type of the Section Header Block is the integer corresponding to the 4-char string "\n\r\n\n" (0x0A0D0D0A). This particular value is used for 2 reasons:

1. This number is used to detect if a file has been transferred via FTP or HTTP from a machine to another with an inappropriate ASCII conversion. In this case, the value of this field will differ from the standard one ("\n\r\n\n") and the reader can detect a possibly corrupted file.

2. This value is palindromic, so that the reader is able to recognize the Section Header Block regardless of the endianness of the section. The endianness is recognized by reading the Byte Order Magic, which is located 8 octets after the Block Type.

* **Block Total Length:** total size of this block, as described in Section 3.1.
* Byte-Order Magic (32 bits): an unsigned magic number, whose value is the hexadecimal number 0x1A2B3C4D. This number can be used to distinguish sections that have been saved on little-endian machines from the ones saved on big-endian machines, and to heuristically identify pcapng files.

* Major Version (16 bits): an unsigned value, giving the number of the current major version of the format. The value for the current version of the format is 1.

* Minor Version (16 bits): an unsigned value, giving the number of the current minor version of the format. The value for the current version of the format is 0.

* Section Length (64 bits): a signed value specifying the length in octets of the following section, excluding the Section Header Block itself. This field can be used to skip the section, for faster navigation inside large files. If the Section Length is -1 (0xFFFFFFFFFFFFFFFF), this means that the size of the section is not specified, and the only way to skip the section is to parse the blocks that it contains. Please note that if this field is valid (i.e. not negative), its value is always a multiple of 4, as all the blocks are aligned to and padded to 32-bit (4 octet) boundaries. Also, special care should be taken in accessing this field: since the alignment of all the blocks in the file is 32-bits, this field is not guaranteed to be aligned to a 64-bit boundary. This could be a problem on 64-bit processors.

* Options: optionally, a list of options (formatted according to the rules defined in Section 3.5) can be present.

Writers of pcapng files MUST NOT write SHBs with a Major Version other than 1 or a Minor Version other than 0. If they do so, they will write a file that many readers of pcapng files, such as programs using libpcap to read pcapng files (including, but not limited to, tcpdump), Wireshark, and possibly other programs not to be able to read their files.

Some pcapng file writers have used a minor version of 2, but the file format did not change incompatibly (new block types were added); Readers of pcapng files MUST treat a Minor Version of 2 as equivalent to a Minor Version of 0 (and, if they also write a pcapng file based on the results of reading one or more pcapng files, they MUST NOT, as per the previous sentence, write an SHB with a Minor Version of 2, even if they read an SHB with a Minor Version of 2). As indicated above, using a minor version number other than 0 when writing a section of a pcapng file will produce a section that most existing software will not be able to read; future versions of some of that
software will be able to read sections with a version of 1.2, but older copies of that software that are not updated to the latest version will still not be able to read them.

The Major Version would be changed only if a new version of this specification, for a later major version of the file format, were created. Such a version would only be created if the format were to change in such a way that code that reads the new format could not read the old format (i.e., code to read both formats would have to check the version number and use different code paths for the two formats) and code that reads the old format could not read the new format. An incompatible change to the format of an existing block or an existing option would be such a change; the addition of a new block or a new option would not be such a change. An example of such an incompatible change would be the addition of an additional field to the Section Header Block, following the Minor Version field and before the Snaplen field; software expecting the new SHB format would not correctly read the old SHB format, and software expecting the old SHB format would not correctly read the new SHB format. (Note that a change to the SHB must leave the Block Type, Block Total Length, Byte-Order Magic, Major Version, and Minor Version fields at the same offsets from the beginning of the SHB and with the same lengths, must keep the value of the Block Type the same, must keep the two possible values of the Byte-Order Magic the same, depending on the block's byte order, so that the rest of the SHB can be correctly interpreted.)

The Minor Version would be changed only if a new version of this specification, for a later minor version of the file format, were created. Such a version would only be created if the format were to change in such a way that code that reads the new format could read the old format without checking the version number but code that reads the old format could not read all files in the new format. A backward-compatible change to the format of an existing block or an existing option would be such a change; the addition of a new block or a new option would not be such a change. An example of such a backward-compatible but not forward-compatible change would be a change to the Interface Description block (see below) to use the current Reserved field to indicate the presence of additional fields before the Options, with a zero value indicate no such fields are present.

I.e., adding new block types or options would not require that either the Major Version or the Minor Version be changed, as code that does not know about the block type or option should just skip it; only if skipping a block or option does not work should the minor version number be changed.
Aside from the options defined in Section 3.5, the following options are valid within this block:

| Name         | Code | Length   | Multiple allowed? |
|--------------+------+----------+-------------------|
| shb_hardware | 2    | variable | no                |
| shb_os       | 3    | variable | no                |
| shb_userappl | 4    | variable | no                |

Table 2: Section Header Block Options

shb_hardware:
The shb_hardware option is a UTF-8 string containing the description of the hardware used to create this section. The string is not zero-terminated.

Examples: "x86 Personal Computer", "Sun Sparc Workstation".

shb_os:
The shb_os option is a UTF-8 string containing the name of the operating system used to create this section. The string is not zero-terminated.

Examples: "Windows XP SP2", "openSUSE 10.2".

shb_userappl:
The shb_userappl option is a UTF-8 string containing the name of the application used to create this section. The string is not zero-terminated.

Examples: "dumpcap V0.99.7".

[Open issue: does a program which re-writes a capture file change the original hardware/os/application info?]

4.2. Interface Description Block

An Interface Description Block (IDB) is the container for information describing an interface on which packet data is captured.

Tools that write / read the capture file associate an incrementing unsigned 32-bit number (starting from ’0’) to each Interface Definition Block, called the Interface ID for the interface in question. This number is unique within each Section and identifies
the interface to which the IDB refers; it is only unique inside the current section, so, two Sections can have different interfaces identified by the same Interface ID values. This unique identifier is referenced by other blocks, such as Enhanced Packet Blocks and Interface Statistic Blocks, to indicate the interface to which the block refers (such the interface that was used to capture the packet that an Enhanced Packet Block contains or to which the statistics in an Interface Statistic Block refer).

There must be an Interface Description Block for each interface to which another block refers. Blocks such as an Enhanced Packet Block or an Interface Statistics Block contain an Interface ID value referring to a particular interface, and a Simple Packet Block implicitly refers to an interface with an Interface ID of 0. If the file does not contain any blocks that use an Interface ID, then the file does not need to have any IDBs.

An Interface Description Block is valid only inside the section to which it belongs. The structure of a Interface Description Block is shown in Figure 10.

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
0 |                    Block Type = 0x00000001                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
4 |                      Block Total Length                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
8 |           LinkType            |           Reserved            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
12 |                            SnapLen                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Options (variable)                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
16 /                                                                 /
/                                                                 /
/                                                                 /
/                                                                 /
/                      Block Total Length                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 10: Interface Description Block Format

The meaning of the fields is:

* Block Type: The block type of the Interface Description Block is 1.

* Block Total Length: total size of this block, as described in Section 3.1.
* LinkType (16 bits): an unsigned value that defines the link layer type of this interface. The list of Standardized Link Layer Type codes is available in [LINKTYPES].

* Reserved (16 bits): not used - MUST be filled with 0 by pcapng file writers, and MUST be ignored by pcapng file readers.

* SnapLen (32 bits): an unsigned value indicating the maximum number of octets captured from each packet. The portion of each packet that exceeds this value will not be stored in the file. A value of zero indicates no limit.

* Options: optionally, a list of options (formatted according to the rules defined in Section 3.5) can be present.

In addition to the options defined in Section 3.5, the following options are valid within this block:
### Table 3: Interface Description Block Options

<table>
<thead>
<tr>
<th>Name</th>
<th>Code</th>
<th>Length</th>
<th>Multiple allowed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>if_name</td>
<td>2</td>
<td>variable</td>
<td>no</td>
</tr>
<tr>
<td>if_description</td>
<td>3</td>
<td>variable</td>
<td>no</td>
</tr>
<tr>
<td>if_IPv4addr</td>
<td>4</td>
<td>8</td>
<td>yes</td>
</tr>
<tr>
<td>if_IPv6addr</td>
<td>5</td>
<td>17</td>
<td>yes</td>
</tr>
<tr>
<td>if_MACaddr</td>
<td>6</td>
<td>6</td>
<td>no</td>
</tr>
<tr>
<td>if_EUIaddr</td>
<td>7</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>if_speed</td>
<td>8</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>if_tsresol</td>
<td>9</td>
<td>1</td>
<td>no</td>
</tr>
<tr>
<td>if_tzone</td>
<td>10</td>
<td>4</td>
<td>no</td>
</tr>
<tr>
<td>if_filter</td>
<td>11</td>
<td>variable, minimum 1</td>
<td>no</td>
</tr>
<tr>
<td>if_os</td>
<td>12</td>
<td>variable</td>
<td>no</td>
</tr>
<tr>
<td>if_fcslen</td>
<td>13</td>
<td>1</td>
<td>no</td>
</tr>
<tr>
<td>if_tsoffset</td>
<td>14</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>if_hardware</td>
<td>15</td>
<td>variable</td>
<td>no</td>
</tr>
<tr>
<td>if_txspeed</td>
<td>16</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>if_rxspeed</td>
<td>17</td>
<td>8</td>
<td>no</td>
</tr>
</tbody>
</table>

if_name:

The if_name option is a UTF-8 string containing the name of the device used to capture data. The string is not zero-terminated.

Examples: "eth0", "\Device\NPF_(AD1CE675-96D0-47C5-ADD0-2504B9126B68)".

if_description:
The if_description option is a UTF-8 string containing the description of the device used to capture data. The string is not zero-terminated.

Examples: "Wi-Fi", "Local Area Connection", "Wireless Network Connection", "First Ethernet Interface".

if_IPv4addr:
The if_IPv4addr option is an IPv4 network address and corresponding netmask for the interface. The first four octets are the IP address, and the next four octets are the netmask. This option can be repeated multiple times within the same Interface Description Block when multiple IPv4 addresses are assigned to the interface. Note that the IP address and netmask are both treated as four octets, one for each octet of the address or mask; they are not 32-bit numbers, and thus the endianness of the SHB does not affect this field’s value.

Examples: ‘192 168 1 1 255 255 255 0’.

if_IPv6addr:
The if_IPv6addr option is an IPv6 network address and corresponding prefix length for the interface. The first 16 octets are the IP address and the next octet is the prefix length. This option can be repeated multiple times within the same Interface Description Block when multiple IPv6 addresses are assigned to the interface.

Example: 2001:0db8:85a3:08d3:1319:8a2e:0370:7344/64 is written (in hex) as ‘20 01 0d b8 85 a3 08 d3 13 19 8a 2e 03 70 73 44 40’.

if_MACaddr:
The if_MACaddr option is the Interface Hardware MAC address (48 bits), if available.

Example: ‘00 01 02 03 04 05’.

if_EUIaddr:
The if_EUIaddr option is the Interface Hardware EUI address (64 bits), if available.

Example: ‘02 34 56 FF FE 78 9A BC’.

if_speed:
The if_speed option is a 64-bit unsigned value indicating the interface speed, in bits per second.
Example: the 64-bit decimal number 100000000 for 100Mbps.

if_tsresol:
The if_tsresol option identifies the resolution of timestamps. If the Most Significant Bit is equal to zero, the remaining bits indicates the resolution of the timestamp as a negative power of 10 (e.g. 6 means microsecond resolution, timestamps are the number of microseconds since 1970-01-01 00:00:00 UTC). If the Most Significant Bit is equal to one, the remaining bits indicates the resolution as negative power of 2 (e.g. 10 means 1/1024 of second). If this option is not present, a resolution of $10^{-6}$ is assumed (i.e. timestamps have the same resolution of the standard 'libpcap' timestamps).

Example: ‘6’.

if_tzone:
The if_tzone option identifies the time zone for GMT support (TODO: specify better).

Example: TODO: give a good example.

if_filter:
The if_filter option identifies the filter (e.g. "capture only TCP traffic") used to capture traffic. The first octet of the Option Data keeps a code of the filter used (e.g. if this is a libpcap string, or BPF bytecode, and more). More details about this format will be presented in Appendix XXX (TODO). (TODO: better use different options for different fields? e.g. if_filter_pcap, if_filter_bpf, ...)

Example: ‘00’"tcp port 23 and host 192.0.2.5".

if_os:
The if_os option is a UTF-8 string containing the name of the operating system of the machine in which this interface is installed. This can be different from the same information that can be contained by the Section Header Block (Section 4.1) because the capture can have been done on a remote machine. The string is not zero-terminated.

Examples: "Windows XP SP2", "openSUSE 10.2".

if_fcslen:
The if_fcslen option is an 8-bit unsigned integer value that specifies the length of the Frame Check Sequence (in bits) for this interface. For link layers whose FCS length can
change during time, the Enhanced Packet Block epb_flags Option can be used in each Enhanced Packet Block (see Section 4.3.1).

Example: '4'.

if_tsoffset:
The if_tsoffset option is a 64-bit signed integer value that specifies an offset (in seconds) that must be added to the timestamp of each packet to obtain the absolute timestamp of a packet. If the option is missing, the timestamps stored in the packet MUST be considered absolute timestamps. The timezone of the offset can be specified with the option if_tzone. TODO: won’t a if_tsoffset_low for fractional second offsets be useful for highly synchronized capture systems?

Example: '1234'.

if_hardware:
The if_hardware option is a UTF-8 string containing the description of the interface hardware. The string is not zero-terminated.

Examples: "Broadcom NetXtreme", "Intel(R) PRO/1000 MT Network Connection", "NETGEAR WNA1000Mv2 N150 Wireless USB Micro Adapter".

if_txspeed:
The if_txrxspeeds option is a 64-bit unsigned value indicating the interface transmit speed in bits per second.

Example: the 64-bit decimal number 1024000 for 1024Kbps.

if_rxspeed:
The if_rxspeed option is a 64-bit unsigned value indicating the interface receive speed, in bits per second.

Example: the 64-bit decimal number 8192000 for 8192Kbps.

If the interface transmit speed and receive speed are the same, the if_speed option MUST be used and the if_txspeed and if_rxspeed options MUST NOT be used. If the transmit speed is unknown, the if_speed and if_txspeed options MUST NOT be used; if the receive speed is unknown, the if_speed and if_rxspeed options MUST NOT be used.
4.3. Enhanced Packet Block

An Enhanced Packet Block (EPB) is the standard container for storing the packets coming from the network. The Enhanced Packet Block is optional because packets can be stored either by means of this block or the Simple Packet Block, which can be used to speed up capture file generation; or a file may have no packets in it. The format of an Enhanced Packet Block is shown in Figure 11.

The Enhanced Packet Block is an improvement over the original, now obsolete, Packet Block (Appendix A):

* it stores the Interface Identifier as a 32-bit integer value. This is a requirement when a capture stores packets coming from a large number of interfaces;

* unlike the Packet Block (Appendix A), the number of packets dropped by the capture system between this packet and the previous one is not stored in the header, but rather in an option of the block itself.
The Enhanced Packet Block has the following fields:

* Block Type: The block type of the Enhanced Packet Block is 6.

* Block Total Length: total size of this block, as described in Section 3.1.

* Interface ID (32 bits): an unsigned value that specifies the interface on which this packet was received or transmitted; the correct interface will be the one whose Interface Description Block (within the current Section of the file) is identified by the same number (see Section 4.2) of this field. The interface ID MUST be valid, which means that an matching interface description block MUST exist.
* Timestamp (High) and Timestamp (Low): upper 32 bits and lower 32 bits of a 64-bit timestamp. The timestamp is a single 64-bit unsigned integer that represents the number of units of time that have elapsed since 1970-01-01 00:00:00 UTC. The length of a unit of time is specified by the 'if_tsresol' option (see Figure 10) of the Interface Description Block referenced by this packet. Note that, unlike timestamps in the libpcap file format, timestamps in Enhanced Packet Blocks are not saved as two 32-bit values that represent the seconds and microseconds that have elapsed since 1970-01-01 00:00:00 UTC. Timestamps in Enhanced Packet Blocks are saved as two 32-bit words that represent the upper and lower 32 bits of a single 64-bit quantity.

* Captured Packet Length (32 bits): an unsigned value that indicates the number of octets captured from the packet (i.e. the length of the Packet Data field). It will be the minimum value among the Original Packet Length and the snapshot length for the interface (SnapLen, defined in Figure 10). The value of this field does not include the padding octets added at the end of the Packet Data field to align the Packet Data field to a 32-bit boundary.

* Original Packet Length (32 bits): an unsigned value that indicates the actual length of the packet when it was transmitted on the network. It can be different from the Captured Packet Length if the packet has been truncated by the capture process.

* Packet Data: the data coming from the network, including link-layer headers. The actual length of this field is Captured Packet Length plus the padding to a 32-bit boundary. The format of the link-layer headers depends on the LinkType field specified in the Interface Description Block (see Section 4.2) and it is specified in the entry for that format in [LINKTYPES].

* Options: optionally, a list of options (formatted according to the rules defined in Section 3.5) can be present.

In addition to the options defined in Section 3.5, the following options are valid within this block:
<table>
<thead>
<tr>
<th>Name</th>
<th>Code</th>
<th>Length</th>
<th>Multiple allowed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>epb_flags</td>
<td>2</td>
<td>4</td>
<td>no</td>
</tr>
<tr>
<td>epb_hash</td>
<td>3</td>
<td>variable, minimum hash type-dependent</td>
<td>yes</td>
</tr>
<tr>
<td>epb_dropcount</td>
<td>4</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>epb_packetid</td>
<td>5</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>epb_queue</td>
<td>6</td>
<td>4</td>
<td>no</td>
</tr>
<tr>
<td>epb_verdict</td>
<td>7</td>
<td>variable, minimum verdict type-dependent</td>
<td>yes</td>
</tr>
</tbody>
</table>

Table 4: Enhanced Packet Block Options

**epb_flags:**
The epb_flags option is a 32-bit flags word containing link-layer information. A complete specification of the allowed flags can be found in Section 4.3.1.

**Example:** '0'.

**epb_hash:**
The epb_hash option contains a hash of the packet. The first octet specifies the hashing algorithm, while the following octets contain the actual hash, whose size depends on the hashing algorithm, and hence from the value in the first octet. The hashing algorithm can be: 2s complement (algorithm octet = 0, size = XXX), XOR (algorithm octet = 1, size=XXX), CRC32 (algorithm octet = 2, size = 4), MD-5 (algorithm octet = 3, size = 16), SHA-1 (algorithm octet = 4, size = 20), Toeplitz (algorithm octet = 5, size = 4). The hash covers only the packet, not the header added by the capture driver: this gives the possibility to calculate it inside the network card. The hash allows easier comparison/merging of different capture files, and reliable data transfer between the data acquisition system and the capture library.

**Examples:** '02 EC 1D 87 97', '03 45 6E C2 17 7C 10 1E 3C 2E 99 6E C2 9A 3D 50 8E'.
epb_dropcount:
The epb_dropcount option is a 64-bit unsigned integer value specifying the number of packets lost (by the interface and the operating system) between this packet and the preceding one for the same interface or, for the first packet for an interface, between this packet and the start of the capture process.

Example: ‘0’.

epb_packetid:
The epb_packetid option is a 64-bit unsigned integer that uniquely identifies the packet. If the same packet is seen by multiple interfaces and there is a way for the capture application to correlate them, the same epb_packetid value must be used. An example could be a router that captures packets on all its interfaces in both directions. When a packet hits interface A on ingress, an EPB entry gets created, TTL gets decremented, and right before it egresses on interface B another EPB entry gets created in the trace file. In this case, two packets are in the capture file, which are not identical but the epb_packetid can be used to correlate them.

Example: ‘0’.

epb_queue:
The epb_queue option is a 32-bit unsigned integer that identifies on which queue of the interface the specific packet was received.

Example: ‘0’.

epb_verdict:
The epb_verdict option stores a verdict of the packet. The verdict indicates what would be done with the packet after processing it. For example, a firewall could drop the packet. This verdict can be set by various components, i.e. Hardware, Linux’s eBPF TC or XDP framework, etc. etc. The first octet specifies the verdict type, while the following octets contain the actual verdict data, whose size depends on the verdict type, and hence from the value in the first octet. The verdict type can be: Hardware (type octet = 0, size = variable), Linux_eBPF_TC (type octet = 1, size = 8 (64-bit unsigned integer), value = TC_ACT_* as defined in the Linux pck_cls.h (https://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git/tree/include/uapi/linux/pkt_cls.h) include), Linux_eBPF_XDP (type octet = 2, size = 8 (64-bit unsigned integer), value = XDP_ACT_* as defined in the Linux xdp.h (https://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git/tree/include/uapi/linux/xdp.h) include).
unsigned integer), value = xdp_action as defined in the Linux
pbf.h (https://git.kernel.org/pub/scm/linux/kernel/git/torval
ds/linux.git/tree/include/uapi/linux/bpf.h) include).

Example: '02 00 00 00 00 00 00 00 02' for Linux_eBPF_XDP with verdict
XDP_PASS.

4.3.1. Enhanced Packet Block Flags Word

The Enhanced Packet Block Flags Word is a 32-bit value that contains
link-layer information about the packet.

The word is encoded as an unsigned 32-bit integer, using the
endianness of the Section Header Block scope it is in. In the
following table, the bits are numbered with 0 being the least-
significant bit and 31 being the most-significant bit of the 32-bit
unsigned integer. The meaning of the bits is the following:

<table>
<thead>
<tr>
<th>Bit Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Inbound / Outbound packet (00 = information not available, 01 = inbound, 10 = outbound)</td>
</tr>
<tr>
<td>2-4</td>
<td>Reception type (000 = not specified, 001 = unicast, 010 = multicast, 011 = broadcast, 100 = promiscuous)</td>
</tr>
<tr>
<td>5-8</td>
<td>FCS length, in octets (0000 if this information is not available). This value overrides the if_fcslen option of the Interface Description Block, and is used with those link layers (e.g. PPP) where the length of the FCS can change during time.</td>
</tr>
<tr>
<td>9-15</td>
<td>Reserved (MUST be set to zero).</td>
</tr>
<tr>
<td>16-31</td>
<td>link-layer-dependent errors (Bit 31 = symbol error, Bit 30 = preamble error, Bit 29 = Start Frame Delimiter error, Bit 28 = unaligned frame error, Bit 27 = wrong Inter Frame Gap error, Bit 26 = packet too short error, Bit 25 = packet too long error, Bit 24 = CRC error, other?? are 16 bit enough?).</td>
</tr>
</tbody>
</table>

Table 5
NOTE: in earlier versions of this specification, the bits were specified as being numbered with 0 being the most-significant bit and 31 being the least-significant bit of the 32-bit unsigned integer, rather than with 0 being the least-significant bit and 31 being the most-significant bit. Several implementations number the bits with 0 being the least-significant bit, and no known implementations number them with 0 being the most-significant bit, so the specification was changed to reflect that reality.

4.4. Simple Packet Block

The Simple Packet Block (SPB) is a lightweight container for storing the packets coming from the network. Its presence is optional.

A Simple Packet Block is similar to an Enhanced Packet Block (see Section 4.3), but it is smaller, simpler to process and contains only a minimal set of information. This block is preferred to the standard Enhanced Packet Block when performance or space occupation are critical factors, such as in sustained traffic capture applications. A capture file can contain both Enhanced Packet Blocks and Simple Packet Blocks: for example, a capture tool could switch from Enhanced Packet Blocks to Simple Packet Blocks when the hardware resources become critical.

The Simple Packet Block does not contain the Interface ID field. Therefore, it MUST be assumed that all the Simple Packet Blocks have been captured on the interface previously specified in the first Interface Description Block.

Figure 12 shows the format of the Simple Packet Block.

```
+-------------------------------+-------------------------------+
| 1                      2                      3                     |
|-------------------------------+-------------------------------|
| 0 | Block Type = 0x00000003 |-------------------------------|
|-------------------------------+-------------------------------|
| 4 | Block Total Length |-------------------------------|
|-------------------------------+-------------------------------|
| 8 | Original Packet Length |-------------------------------|
|-------------------------------+-------------------------------|
| 12 / | Packet Data |-------------------------------|
|-------------------------------+-------------------------------|
| / | variable length, padded to 32 bits |-------------------------------|
|-------------------------------+-------------------------------|
| / |-------------------------------+-------------------------------|
|-------------------------------+-------------------------------|
+-------------------------------+-------------------------------|
```
The Simple Packet Block has the following fields:

* Block Type: The block type of the Simple Packet Block is 3.

* Block Total Length: total size of this block, as described in Section 3.1.

* Original Packet Length (32 bits): an unsigned value indicating the actual length of the packet when it was transmitted on the network. It can be different from length of the Packet Data field’s length if the packet has been truncated by the capture process, in which case the SnapLen value in Section 4.2 will be less than this Original Packet Length value, and the SnapLen value MUST be used to determine the size of the Packet Data field length.

* Packet Data: the data coming from the network, including link-layer headers. The length of this field can be derived from the field Block Total Length, present in the Block Header, and it is the minimum value among the SnapLen (present in the Interface Description Block) and the Original Packet Length (present in this header). The format of the data within this Packet Data field depends on the LinkType field specified in the Interface Description Block (see Section 4.2) and it is specified in the entry for that format in [LINKTYPES].

The Simple Packet Block does not contain the timestamp because this is often one of the most costly operations on PCs. Additionally, there are applications that do not require it; e.g. an Intrusion Detection System is interested in packets, not in their timestamp.

A Simple Packet Block cannot be present in a Section that has more than one interface because of the impossibility to refer to the correct one (it does not contain any Interface ID field).

The Simple Packet Block is very efficient in term of disk space: a snapshot whose length is 100 octets requires only 16 octets of overhead, which corresponds to an efficiency of more than 86%.
4.5. Name Resolution Block

The Name Resolution Block (NRB) is used to support the correlation of numeric addresses (present in the captured packets) and their corresponding canonical names and it is optional. Having the literal names saved in the file prevents the need for performing name resolution at a later time, when the association between names and addresses may be different from the one in use at capture time. Moreover, the NRB avoids the need for issuing a lot of DNS requests every time the trace capture is opened, and also provides name resolution when reading the capture with a machine not connected to the network.

A Name Resolution Block is often placed at the beginning of the file, but no assumptions can be taken about its position. Multiple NRBS can exist in a pcapng file, either due to memory constraints or because additional name resolutions were performed by file processing tools, like network analyzers.

A Name Resolution Block need not contain any Records, except the nrb_record_end Record which MUST be the last Record. The addresses and names in NRB Records MAY be repeated multiple times; i.e., the same IP address may resolve to multiple names, the same name may resolve to the multiple IP addresses, and even the same address-to-name pair may appear multiple times, in the same NRB or across NRBS.

The format of the Name Resolution Block is shown in Figure 13.
The Name Resolution Block has the following fields:

* Block Type: The block type of the Name Resolution Block is 4.

* Block Total Length: total size of this block, as described in Section 3.1.

This is followed by zero or more Name Resolution Records (in the TLV format), each of which contains an association between a network address and a name. An nrb_record_end MUST be added after the last Record, and MUST exist even if there are no other Records in the NRB. There are currently three possible types of records:
<table>
<thead>
<tr>
<th>Name</th>
<th>Code</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>nrb_record_end</td>
<td>0x0000</td>
<td>0</td>
</tr>
<tr>
<td>nrb_record_ipv4</td>
<td>0x0001</td>
<td>variable</td>
</tr>
<tr>
<td>nrb_record_ipv6</td>
<td>0x0002</td>
<td>variable</td>
</tr>
</tbody>
</table>

Table 6: Name Resolution Block Records

nrb_record_end:
The nrb_record_end record delimits the end of name resolution records. This record is needed to determine when the list of name resolution records has ended and some options (if any) begin.

nrb_record_ipv4:
The nrb_record_ipv4 record specifies an IPv4 address (contained in the first 4 octets), followed by one or more zero-terminated UTF-8 strings containing the DNS entries for that address. The minimum valid Record Length for this Record Type is thus 6: 4 for the IP octets, 1 character, and a zero-value octet terminator. Note that the IP address is treated as four octets, one for each octet of the IP address; it is not a 32-bit word, and thus the endianness of the SHB does not affect this field’s value.

Example: '127 0 0 1’"localhost".

[Open issue: is an empty string (i.e., just a zero-value octet) valid?]

nrb_record_ipv6:
The nrb_record_ipv6 record specifies an IPv6 address (contained in the first 16 octets), followed by one or more zero-terminated strings containing the DNS entries for that address. The minimum valid Record Length for this Record Type is thus 18: 16 for the IP octets, 1 character, and a zero-value octet terminator.

Example: '20 01 0d b8 00 00 00 00 00 00 00 00 00 12 34 56 78’"somehost".

[Open issue: is an empty string (i.e., just a zero-value octet) valid?]
Record Types other than those specified earlier MUST be ignored and skipped past. More Record Types will likely be defined in the future, and MUST NOT break backwards compatibility.

Each Record Value is aligned to and padded to a 32-bit boundary. The corresponding Record Value Length reflects the actual length of the Record Value; it does not include the lengths of the Record Type field, the Record Value Length field, any padding for the Record Value, or anything after the Record Value. For Record Types with name strings, the Record Length does include the zero-value octet terminating that string. A Record Length of 0 is valid, unless indicated otherwise.

After the list of Name Resolution Records, optionally, a list of options (formatted according to the rules defined in Section 3.5) can be present.

In addition to the options defined in Section 3.5, the following options are valid within this block:

<table>
<thead>
<tr>
<th>Name</th>
<th>Code</th>
<th>Length</th>
<th>Multiple allowed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>ns_dnsname</td>
<td>2</td>
<td>variable</td>
<td>no</td>
</tr>
<tr>
<td>ns_dnsIP4addr</td>
<td>3</td>
<td>4</td>
<td>no</td>
</tr>
<tr>
<td>ns_dnsIP6addr</td>
<td>4</td>
<td>16</td>
<td>no</td>
</tr>
</tbody>
</table>

Table 7: Name Resolution Block Options

ns_dnsname:  
The ns_dnsname option is a UTF-8 string containing the name of the machine (DNS server) used to perform the name resolution. The string is not zero-terminated.

Example: "our_nameserver".

ns_dnsIP4addr:  
The ns_dnsIP4addr option specifies the IPv4 address of the DNS server. Note that the IP address is treated as four octets, one for each octet of the IP address; it is not a 32-bit word, and thus the endianness of the SHB does not affect this field’s value.

Example: ’192 168 0 1’.
ns_dnsIP6addr:
The ns_dnsIP6addr option specifies the IPv6 address of the DNS server.

Example: ‘20 01 0d b8 00 00 00 00 00 00 12 34 56 78’.

4.6. Interface Statistics Block

The Interface Statistics Block (ISB) contains the capture statistics for a given interface and it is optional. The statistics are referred to the interface defined in the current Section identified by the Interface ID field. An Interface Statistics Block is normally placed at the end of the file, but no assumptions can be taken about its position – it can even appear multiple times for the same interface.

The format of the Interface Statistics Block is shown in Figure 14.

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---------------------------------------------------------------+
<table>
<thead>
<tr>
<th>Block Type = 0x00000005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block Total Length</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Interface ID</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Timestamp (High)</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Timestamp (Low)</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
</tbody>
</table>
\| Options (variable)                                            |
\|---------------------------------------------------------------|
\| Block Total Length                                            |
\|---------------------------------------------------------------|
```

Figure 14: Interface Statistics Block Format

The fields have the following meaning:

* Block Type: The block type of the Interface Statistics Block is 5.
* Block Total Length: total size of this block, as described in Section 3.1.
* Interface ID: specifies the interface these statistics refers to; the correct interface will be the one whose Interface Description Block (within the current Section of the file) is identified by the same number (see Section 4.2) of this field.

* Timestamp: time this statistics refers to. The format of the timestamp is the same already defined in the Enhanced Packet Block (Section 4.3); the length of a unit of time is specified by the 'if_tsresol' option (see Figure 10) of the Interface Description Block referenced by this packet.

* Options: optionally, a list of options (formatted according to the rules defined in Section 3.5) can be present.

All the statistic fields are defined as options in order to deal with systems that do not have a complete set of statistics. Therefore, in addition to the options defined in Section 3.5, the following options are valid within this block:

<table>
<thead>
<tr>
<th>Name</th>
<th>Code</th>
<th>Length</th>
<th>Multiple allowed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>isb_starttime</td>
<td>2</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>isb_endtime</td>
<td>3</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>isb_ifrecv</td>
<td>4</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>isb_ifdrop</td>
<td>5</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>isb_filteraccept</td>
<td>6</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>isb_osdrop</td>
<td>7</td>
<td>8</td>
<td>no</td>
</tr>
<tr>
<td>isb_usrdeliv</td>
<td>8</td>
<td>8</td>
<td>no</td>
</tr>
</tbody>
</table>

Table 8: Interface Statistics Block Options

**isb_starttime:**

The isb_starttime option specifies the time the capture started; time will be stored in two blocks of four octets each. The format of the timestamp is the same as the one defined in the Enhanced Packet Block (Section 4.3); the length of a unit of time is specified by the 'if_tsresol' option (see Figure 10) of the Interface Description Block referenced by this packet.
Example: ‘96 c3 04 00 73 89 6a 65’, in Little Endian, decodes to 2012-06-29 06:17:00.834163 UTC.

**isb_endtime:**

The isb_endtime option specifies the time the capture ended; time will be stored in two blocks of four octets each. The format of the timestamp is the same as the one defined in the Enhanced Packet Block (Section 4.3); the length of a unit of time is specified by the ‘if_tsresol’ option (see Figure 10) of the Interface Description Block referenced by this packet.

Example: ‘97 c3 04 00 aa 47 ca 64’, in Little Endian, decodes to 2012-06-29 07:28:25.298858 UTC.

**isb_ifrecv:**

The isb_ifrecv option specifies the 64-bit unsigned integer number of packets received from the physical interface starting from the beginning of the capture.

Example: the decimal number 100.

**isb_ifdrop:**

The isb_ifdrop option specifies the 64-bit unsigned integer number of packets dropped by the interface due to lack of resources starting from the beginning of the capture.

Example: ’0’.

**isb_filteraccept:**

The isb_filteraccept option specifies the 64-bit unsigned integer number of packets accepted by filter starting from the beginning of the capture.

Example: the decimal number 100.

**isb_osdrop:**

The isb_osdrop option specifies the 64-bit unsigned integer number of packets dropped by the operating system starting from the beginning of the capture.

Example: ’0’.

**isb_usrdeliv:**
The isb_usrdeliv option specifies the 64-bit unsigned integer number of packets delivered to the user starting from the beginning of the capture. The value contained in this field can be different from the value 'isb_filteraccept - isb_osdrop' because some packets could still be in the OS buffers when the capture ended.

Example: ‘0’.

All the fields that refer to packet counters are 64-bit values, represented with the octet order of the current section. Special care must be taken in accessing these fields: since all the blocks are aligned to a 32-bit boundary, such fields are not guaranteed to be aligned on a 64-bit boundary.

4.7. Decryption Secrets Block

A Decryption Secrets Block (DSB) stores (session) secrets that enable decryption of packets within the capture file. The format of these secrets is defined by the Secrets Type.

Multiple DSBs can exist in a pcapng file, but they SHOULD be written before packet blocks that require those secrets. Tools MAY limit decryption to secrets that appear before packet blocks.

The structure of a Decryption Secrets Block is shown in Figure 15.
Figure 15: Decryption Secrets Block Format

The Decryption Secrets Block has the following fields.

* Block Type: The block type of the Decryption Secrets Block is 10.

* Block Total Length: total size of this block, as described in Section 3.1.

* Secrets Type (32 bits): an unsigned integer identifier that describes the format of the following Secrets field. Requests for new Secrets Type codes should be made by creating a pull request to update this document as described in Section 10.1.

* Secrets Length (32 bits): an unsigned integer that indicates the size of the following Secrets field, without any padding octets.

* Secrets Data: binary data containing secrets, padded to a 32 bit boundary.

* Options: optionally, a list of options (formatted according to the rules defined in Section 3.5) can be present. No DSB-specific options are currently defined.

The following is a list of Secrets Types.
0x544c534b:
TLS Key Log. This format is described at NSS Key Log Format
(https://developer.mozilla.org/en-US/docs/Mozilla/Projects/NSS/Key_Log_Format). Every line
MUST be properly terminated with either carriage return and
linefeed ('\r\n') or linefeed ('\n'). Tools MUST be able to
handle both line endings.

0x57474b4c:
WireGuard Key Log. Every line consists of the key type,
equals sign ('='), and the base64-encoded 32-byte key with
optional spaces before and in between. The key type is one
of LOCAL_STATIC_PRIVATE_KEY, REMOTE_STATIC_PUBLIC_KEY,
LOCAL_EPHEMERAL_PRIVATE_KEY, or PRESHARED_KEY. This matches
the output of extract-handshakes.sh
(https://git.zx2c4.com/WireGuard/tree/contrib/examples/
extract-handshakes/README), which is part of the WireGuard
(https://www.wireguard.com/) project. A PRESHARED_KEY line
is linked to a session matched by a previous
LOCAL_EPHEMERAL_PRIVATE_KEY line. Every line MUST be
properly terminated with either carriage return and linefeed
('\r\n') or linefeed ('\n'). Tools MUST be able to handle
both line endings.

Warning: LOCAL_STATIC_PRIVATE_KEY and potentially PRESHARED_KEY are
long-term secrets, users SHOULD only store non-production keys, or
ensure proper protection of the pcapng file.

0x5a4e574b:
ZigBee NWK Key and ZigBee PANID for that network. Network
Key as described in the ZigBee Specification
(https://zigbeealliance.org/) 05-3473-21 (R21) section 4.2.2.
The NWK Key is a 16 octet binary AES-128 key used to secure
NWK Level frames within a single PAN. The NWK key is
immediately followed by the 2 octet (16 bit) network PANID in
little endian format. If and when the NWK Key changes a new
DSB will contain the new NWK Key.

0x5a4e574b:
ZigBee APS Key. Application Support Link Key as described in
the ZigBee Specification (https://zigbeealliance.org/) 05-3473-21 (R21) section 4.4. Each 16 octet binary AES-128
key secures frames exchanged between a pair of network nodes.
The APS Key is immediately followed by the 2 octet (16 bit)
network PANID in little endian format. The PANID is followed
by the 2 octet (16 bit) short addresses, in little endian
format, of the nodes to which the APS Key applies. The
numerically lower short address shall come first. There is a
APS Key DSB for each node pair for which the Link Key is known. As new links are formed, new DSBs contain the new Keys. If the APS Key changes for an existing link, it is contained in a new DSB with the new APS Key.

![ZigBee NWK Key Data Format](image)

Figure 16: ZigBee NWK Key Data Format
4.8. Custom Block

A Custom Block (CB) is the container for storing custom data that is not part of another block; for storing custom data as part of another block, see Section 3.5.1. The Custom Block is optional, can be repeated any number of times, and can appear before or after any other block except the first Section Header Block which must come first in the file. Different Custom Blocks, of different type codes and/or different Private Enterprise Numbers, may be used in the same pcapng file. The format of a Custom Block is shown in Figure 18.
The Custom Block uses the type code 0x00000BAD (2989 in decimal) for a custom block that pcapng re-writers can copy into new files, and the type code 0x40000BAD (1073744813 in decimal) for one that should not be copied. See Section 5.2 for details.

The Custom Block has the following fields:

* Block Type: The block type of the Custom Block is 0x00000BAD or 0x40000BAD, as described previously.

* Block Total Length: total size of this block, as described in Section 3.1.

* Private Enterprise Number (32 bits): An IANA-assigned Private Enterprise Number identifying the organization which defined the Custom Block. See Section 5.1 for details. The PEN MUST be encoded using the same endianness as the Section Header Block it is within the scope of.

* Custom Data: the custom data, padded to a 32 bit boundary.

* Options: optionally, a list of options (formatted according to the rules defined in Section 3.5) can be present. Note that custom options for the Custom Block still use the custom option format and type code, as described in Section 3.5.1.
5. Vendor-Specific Custom Extensions

This section uses the term "vendor" to describe an organization which extends the pcapng file with custom, proprietary blocks or options. It should be noted, however, that the "vendor" is just an abstract entity that agrees on a custom extension format: for example it may be a manufacturer, industry association, an individual user, or collective group of users.

5.1. Supported Use-Cases

There are two different supported use-cases for vendor-specific custom extensions: local and portable. Local use means the custom data is only expected to be usable on the same machine, and the same application, which encoded it into the file. This limitation is due to the lack of a common registry for the local use number codes (the block or option type code numbers with the Most Significant Bit set). Since two different vendors may choose the same number, one vendor’s application reading the other vendor’s file would result in decoding failure. Therefore, vendors SHOULD instead use the portable method, as described next.

The portable use-case supports vendor-specific custom extensions in pcapng files which can be shared across systems, organizations, etc. To avoid number space collisions, an IANA-registered Private Enterprise Number (PEN) is encoded into the Custom Block or Custom Option, using the PEN that belongs to the vendor defining the extension. Anyone can register a new PEN with IANA, for free, by filling out the online request form at http://pen.iana.org/pen/PenApplication.page (http://pen.iana.org/pen/PenApplication.page).
5.2. Controlling Copy Behavior

Both Custom Blocks and Custom Options support two different codes to distinguish their "copy" behavior: a code for when the block or option can be safely copied into a new pcapng file by a pcapng manipulating application, and a code for when it should not be copied. A common reason for not copying a Custom Block or Custom Option is because it depends on other blocks or options in some way that would invalidate the custom data if the other blocks/options were removed or re-ordered. For example, if a Custom Block's data includes an Interface ID number in its Custom Data portion, then it cannot be safely copied by a pcapng application that merges pcapng files, because the merging application might re-order or remove one or more of the Interface Description Blocks, and thereby change the Interface IDs that the Custom Block depends upon. The same issue arises if a Custom Block or Custom Option depends on the presence of, or specific ordering of, other standard-based or custom-defined blocks or options.

Note that the copy semantics is not related to privacy - there is no guarantee that a pcapng anonymizer will remove a Custom Block or Custom Option, even if the appropriate code is used requesting it not be copied; and the original pcapng file can be shared anyway. If the Custom Data portion of the Custom Block or Custom Option contains sensitive information, then it should be encrypted in some fashion.

5.3. Strings vs. Octets

For the Custom Options, there are two Custom Data formats supported: a UTF-8 string and a binary data payload. The rationale for this separation is that a pcapng display application which does not understand the specific PEN's Custom Option can still display the data as a string if it's a string type code, rather than as hex-ascii of the octets.

5.4. Endianness Issues

Implementers writing Custom Blocks or binary data Custom Options should be aware that a pcapng file can be re-written by machines using a different endianness than the original file, which means all known fields of the pcapng file will change endianness in the new file. Since the Custom Data payload of the Custom Block or the binary data Custom Option might be an arbitrary sequence of unknown octets to such machines, they cannot convert multi-octet values inside the Custom Data, or in the Options section of a Custom Block, into the appropriate endianness.
For example, a little-endian machine can create a new pcapng file and add some binary data Custom Options to some non-Custom Block(s) in the file. This file can then be sent to a big-endian host, which will convert the Option Code, Option Length, and PEN fields of the options to big-endian format if it re-writes the file. However, if the software reading the file does not understand the contents of all of the Custom Options, it will leave the Custom Data payload of the options alone (as little-endian format). If this file then gets sent to a little-endian machine, then, when that little-endian machine reads the file, it will, if the software reading the file understands the contents of all the Custom Options, it will detect that the file format is big-endian, and swap the endianness while it parses the file - but that will cause the Custom Data payload to be incorrect since it was already in little-endian format.

In addition, a little-endian machine can create a pcapng file and write some binary data Custom Blocks, containing options, to the file. The file can then be sent to a big-endian host, which, if the software reading the file does not understand the contents of the Custom Blocks, will leave the Custom Data and Options alone (as little-endian format). If this file then gets sent to a little-endian machine, then, when that little-endian machine reads the file, it will, if the software reading the file understands the contents of all the Custom Blocks, it will detect that the file format is big-endian, and swap the endianness while it parses the file - but that will cause the Custom Data payload, the Option Code and Option Length values in the Options, and the PEN in any Custom Options to be incorrect since they were already in little-endian format.

Therefore, the vendor should either encode the Custom Data of their Custom Blocks and Custom Options, the Option Code and Option Length fields of options in Custom Blocks, and the PEN field of Custom Options in Custom Blocks in a consistent manner, such as always in big-endian or always in little-endian format, regardless of the host platform's endianness, or should encode some flag in the Custom Data payload to indicate in which endianness the rest of the payload is written.

The PEN field of a Custom Block, or of a Custom Option not contained in a Custom Block, MUST be converted by code that reads pcapng files, so this is not an issue for that field, except for Custom Options in Custom Blocks. This is also not an issue for the Custom Data payload of UTF-8 string Custom Options.

6. Recommended File Name Extension: .pcapng

The recommended file name extension for the "PCAP Next Generation Capture File Format" specified in this document is ".pcapng".
On Windows and macOS, files are distinguished by an extension to their filename. Such an extension is technically not actually required, as applications should be able to automatically detect the pcapng file format through the "magic bytes" at the beginning of the file, as some other UN*X desktop environments do. However, using name extensions makes it easier to work with files (e.g. visually distinguish file formats) so it is recommended - though not required - to use .pcapng as the name extension for files following this specification.

Please note: To avoid confusion (such as the current usage of .cap for a plethora of different capture file formats) file name extensions other than .pcapng should be avoided.

7. Conclusions

The file format proposed in this document should be very versatile and satisfy a wide range of applications. In the simplest case, it can contain a raw capture of the network data, made of a series of Simple Packet Blocks. In the most complex case, it can be used as a repository for heterogeneous information. In every case, the file remains easy to parse and an application can always skip the data it is not interested in; at the same time, different applications can share the file, and each of them can benefit of the information produced by the others. Two or more files can be concatenated obtaining another valid file.

8. Implementations

Some known implementations that read or write the pcapng file format are listed on the pcapng GitHub wiki (https://github.com/pcapng/pcapng/wiki/Implementations).

9. Security Considerations

TBD.

10. IANA Considerations

TBD.

[Open issue: decide whether the block types, option types, NRB Record types, etc. should be IANA registries. And if so, what the IANA policy for each should be (see RFC 5226)]
10.1. Standardized Block Type Codes

Every Block is uniquely identified by a 32-bit integer value, stored in the Block Header.

As pointed out in Section 3.1, Block Type codes whose Most Significant Bit (bit 31) is set to 1 are reserved for local use by the application.

All the remaining Block Type codes (0x00000000 to 0x7FFFFFFF) are standardized by this document. Requests for new Block Type codes, Option Type codes, and Secrets Type codes should be made by creating a pull request to update this document at github.com/pcapng/pcapng (https://github.com/pcapng/pcapng). The pull request should add a description of the new block, option, or secret type to Section 4. The pull request description should contain a clear request for a new type code assignment.

The following is a list of the Standardized Block Type Codes:

<table>
<thead>
<tr>
<th>Block Type Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00000000</td>
<td>Reserved ???</td>
</tr>
<tr>
<td>0x00000001</td>
<td>Interface Description Block (Section 4.2)</td>
</tr>
<tr>
<td>0x00000002</td>
<td>Packet Block (Appendix A)</td>
</tr>
<tr>
<td>0x00000003</td>
<td>Simple Packet Block (Section 4.4)</td>
</tr>
<tr>
<td>0x00000004</td>
<td>Name Resolution Block (Section 4.5)</td>
</tr>
<tr>
<td>0x00000005</td>
<td>Interface Statistics Block (Section 4.6)</td>
</tr>
<tr>
<td>0x00000006</td>
<td>Enhanced Packet Block (Section 4.3)</td>
</tr>
<tr>
<td>0x00000007</td>
<td>IRIG Timestamp Block (requested by Gianluca Varenni <a href="mailto:gianluca.varenni@cacetech.com">gianluca.varenni@cacetech.com</a>, CACE Technologies LLC); code also used for Socket Aggregation Event Block (<a href="https://github.com/google/linux-sensor/blob/master/hone-pcapng.txt">https://github.com/google/linux-sensor/blob/master/hone-pcapng.txt</a>)</td>
</tr>
<tr>
<td>0x00000008</td>
<td>ARINC 429 (<a href="https://en.wikipedia.org/wiki/ARINC_429">https://en.wikipedia.org/wiki/ARINC_429</a>) in AFDX Encapsulation Information Block (requested by Gianluca Varenni <a href="mailto:gianluca.varenni@cacetech.com">gianluca.varenni@cacetech.com</a>, CACE)</td>
</tr>
<tr>
<td>Offset</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>0x00000009</td>
<td>[systemd Journal Export Block][I-D.richardson-opsawg-pcapng-extras]</td>
</tr>
<tr>
<td>0x0000000A</td>
<td>Decryption Secrets Block (Section 4.7)</td>
</tr>
<tr>
<td>0x00000101</td>
<td>Hone Project (<a href="https://github.com/HoneProject">https://github.com/HoneProject</a>) Machine Info Block</td>
</tr>
<tr>
<td>0x00000102</td>
<td>Hone Project (<a href="https://github.com/HoneProject">https://github.com/HoneProject</a>) Connection Event Block</td>
</tr>
<tr>
<td>0x00000201</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Machine Info Block</td>
</tr>
<tr>
<td>0x00000202</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Process Info Block, version 1</td>
</tr>
<tr>
<td>0x00000203</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) FD List Block</td>
</tr>
<tr>
<td>0x00000204</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Event Block</td>
</tr>
<tr>
<td>0x00000205</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Interface List Block</td>
</tr>
<tr>
<td>0x00000206</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) User List Block</td>
</tr>
<tr>
<td>0x00000207</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Process Info Block, version 2</td>
</tr>
<tr>
<td>0x00000208</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Event Block with flags</td>
</tr>
<tr>
<td>0x00000209</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>)</td>
</tr>
<tr>
<td>Offset</td>
<td>Block Description</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>0x00000210</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Process Info Block, version 4</td>
</tr>
<tr>
<td>0x00000211</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Process Info Block, version 5</td>
</tr>
<tr>
<td>0x00000212</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Process Info Block, version 6</td>
</tr>
<tr>
<td>0x00000213</td>
<td>Sysdig (<a href="https://github.com/draios/sysdig">https://github.com/draios/sysdig</a>) Process Info Block, version 7</td>
</tr>
<tr>
<td>0x00000BAD</td>
<td>Custom Block that rewriters can copy into new files (Section 4.8)</td>
</tr>
<tr>
<td>0x40000BAD</td>
<td>Custom Block that rewriters should not copy into new files (Section 4.8)</td>
</tr>
<tr>
<td>0x0A0D0D0A</td>
<td>Section Header Block (Section 4.1)</td>
</tr>
<tr>
<td>0x0A0D0A00-0x0A0D0AFF</td>
<td>Reserved. Used to detect trace files corrupted because of file transfers using the HTTP protocol in text mode.</td>
</tr>
<tr>
<td>0x000A0D0A-0xFF0A0D0A</td>
<td>Reserved. Used to detect trace files corrupted because of file transfers using the HTTP protocol in text mode.</td>
</tr>
<tr>
<td>0x000A0D0D-0xFF0A0D0D</td>
<td>Reserved. Used to detect trace files corrupted because of file transfers using the HTTP protocol in text mode.</td>
</tr>
<tr>
<td>0xD0D0A00-0xD0D0A0FF</td>
<td>Reserved. Used to detect trace files corrupted because of file transfers using the FTP protocol in text mode.</td>
</tr>
<tr>
<td>0x80000000-0xFFFFFFFF</td>
<td>Reserved for local use.</td>
</tr>
</tbody>
</table>

Table 9: Standardized Block Type Codes

[Open issue: reserve 0x40000000-0x7FFFFFFF for do-not-copy-bit range of base types?]
11. Contributors

Loris Degioanni and Gianluca Varenni were coauthoring this document before it was submitted to the IETF.

12. Acknowledgments

The authors wish to thank Anders Broman, Ulf Lamping, Richard Sharpe and many others for their invaluable comments.

13. References

13.1. Normative References


13.2. Informative References

[I-D.richardson-opsawg-pcapng-extras] "*** BROKEN REFERENCE ***".


Appendix A. Packet Block (obsolete!)

The Packet Block is obsolete, and MUST NOT be used in new files. Use the Enhanced Packet Block or Simple Packet Block instead. This section is for historical reference only.

A Packet Block was a container for storing packets coming from the network.
The Packet Block has the following fields:

* Block Type: The block type of the Packet Block is 2.

* Block Total Length: total size of this block, as described in Section 3.1.

* Interface ID: specifies the interface this packet comes from; the correct interface will be the one whose Interface Description Block (within the current Section of the file) is identified by the same number (see Section 4.2) of this field. The interface ID MUST be valid, which means that an matching interface description block MUST exist.
* Drops Count: a local drop counter. It specifies the number of packets lost (by the interface and the operating system) between this packet and the preceding one. The value xFFFF (in hexadecimal) is reserved for those systems in which this information is not available.

* Timestamp (High) and Timestamp (Low): timestamp of the packet. The format of the timestamp is the same as was already defined for the Enhanced Packet Block (Section 4.3).

* Captured Packet Length: number of octets captured from the packet (i.e. the length of the Packet Data field). It will be the minimum value among the Original Packet Length and the snapshot length for the interface (SnapLen, defined in Figure 10). The value of this field does not include the padding octets added at the end of the Packet Data field to align the Packet Data field to a 32-bit boundary.

* Original Packet Length: actual length of the packet when it was transmitted on the network. It can be different from Captured Packet Length if the packet has been truncated by the capture process.

* Packet Data: the data coming from the network, including link-layer headers. The actual length of this field is Captured Packet Length plus the padding to a 32-bit boundary. The format of the link-layer headers depends on the LinkType field specified in the Interface Description Block (see Section 4.2) and it is specified in the entry for that format in [LINKTYPES].

* Options: optionally, a list of options (formatted according to the rules defined in Section 3.5) can be present.

In addition to the options defined in Section 3.5, the following options were valid within this block:

<table>
<thead>
<tr>
<th>Name</th>
<th>Code</th>
<th>Length</th>
<th>Multiple allowed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>pack_flags</td>
<td>2</td>
<td>4</td>
<td>no</td>
</tr>
<tr>
<td>pack_hash</td>
<td>3</td>
<td>variable</td>
<td>yes</td>
</tr>
</tbody>
</table>

Table 10: Packet Block Options

pack_flags:
The pack_flags option is the same as the epb_flags of the enhanced packet block.

Example: '0'.

pack_hash:
The pack_hash option is the same as the epb_hash of the enhanced packet block.

Examples: '02 EC 1D 87 97', '03 45 6E C2 17 7C 10 1E 3C 2E 99 6E C2 9A 3D 50 8E'.

Authors’ Addresses

Michael Tuexen (editor)
Muenster University of Applied Sciences
Stegerwaldstrasse 39
48565 Steinfurt
Germany

Email: tuexen@fh-muenster.de

Fulvio Risso
Politecnico di Torino
Corso Duca degli Abruzzi, 24
10129 Torino
Italy

Email: fulvio.risso@polito.it

Jasper Bongertz
Airbus Defence and Space CyberSecurity
Kanzlei 63c
40667 Meerbusch
Germany

Email: jasper@packet-foo.com

Gerald Combs
Wireshark Foundation
339 Madson Pl
Davis, CA 95618
United States of America

Email: gerald@wireshark.org
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Abstract

This document updates the TLS Transport Model (TLSTM), as defined in [RFC6353], to support Transport Layer Security Version 1.3 (TLS) [RFC8446] and Datagram Transport Layer Security Version 1.3 (DTLS) [I-D.ietf-tls-dtls-13], which are jointly known as "(D)TLS". This document may be applicable to future versions of SNMP and (D)TLS.

This document updates the SNMP-TLS-TM-MIB as defined in [RFC6353].

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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This document updates the fingerprint algorithm defined by [RFC6353] to support the ciphersuites used by Transport Layer Security Version 1.3 (TLS) and Datagram Transport Layer Security Version 1.3 (DTLS), which are jointly known as "(D)TLS". The update also incorporates other less critical updates. Although the title and text of this document specifically reference SNMPv3 and (D)TLS 1.3, this document may be applicable to future versions of these protocols.
1.1. Conventions

Within this document the terms "TLS", "DTLS", "(D)TLS", "SNMP", and "TLSTM" mean "TLS 1.3", "DTLS 1.3", "TLS 1.3 and/or DTLS 1.3", "SNMPv3", and "TLSTM 1.3", respectively. These version numbers are only used when the text needs to emphasize version numbers, such as within the title. When this document refers to any other version of these protocols, it always explicitly states the version intended.

For consistency with SNMP-related specifications, this document favors terminology as defined in [STD62], rather than favoring terminology that is consistent with non-SNMP specifications. This is consistent with the IESG decision to not require the SNMPv3 terminology be modified to match the usage of other non-SNMP specifications when SNMPv3 was advanced to a Full Standard. "Authentication" in this document typically refers to the English meaning of "serving to prove the authenticity of" the message, not data source authentication or peer identity authentication. The terms "manager" and "agent" are not used in this document because, in the RFC3411 architecture, all SNMP entities have the capability of acting as manager, agent, or both depending on the SNMP application types supported in the implementation. Where distinction is necessary, the application names of command generator, command responder, notification originator, notification receiver, and proxy forwarder are used. See "SNMP Applications" (RFC3411) for further information.

Throughout this document, the terms "client" and "server" are used to refer to the two ends of the TLS transport connection. The client actively opens the TLS connection, and the server passively listens for the incoming TLS connection. An SNMP entity MAY act as a TLS client or server or both, depending on the SNMP applications supported.

While TLS frequently refers to a user, the terminology preferred in RFC3411 and in this memo is "principal". A principal is the "who" on whose behalf services are provided or processing takes place. A principal can be, among other things, an individual acting in a particular role; a set of individuals, with each acting in a particular role; an application or a set of applications, or a combination of these within an administrative domain.
Throughout this document, the term "session" is used to refer to a secure association between two TLS Transport Models that permits the transmission of one or more SNMP messages within the lifetime of the session. The TLS protocol also has an internal notion of a session and although these two concepts of a session are related, when the term "session" is used this document is referring to the TLSTM’s specific session and not directly to the TLS protocol’s session.

The User-Based Security Model (USM) (RFC3414) is a mandatory-to-implement Security Model in [STD62]. The USM derives the securityName and securityLevel from the SNMP message received, even when the message was received over a secure transport. It is RECOMMENDED that deployments that support the TLSTM disable the USM, if it has been implemented.

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].

2. Changes from RFC 6353

This document updates [RFC6353]. The changes from [RFC6353] are defined in the following clauses.

2.1. TLSTM Fingerprint

[RFC6353] defines a fingerprint algorithm that references the one-octet TLS 1.2 hash algorithm identifier. TLS 1.3 replaced the one-octet hash algorithm identifier with a two-octet TLS 1.3 cipher suite identifier thereby breaking the algorithm defined in [RFC6353]. The update to the SNMP-TLS-TM-MIB, as defined in Section 4, deprecates the original fingerprint TEXTUAL-CONVENTION and replaces it with a new TEXTUAL-CONVENTION.

The change also required an update to several objects within the tables defined within the SNMP-TLS-TM-MIB; further these objects are referenced by other (e.g., RowStatus) objects in a manner that requires deprecating and replacing the tables in their entirety. Thus, while the number of objects deprecated and replaced is significant the semantics of the changes are minor.

References to the older objects within [RFC6353] are applicable to the replacement objects. The newer objects are identified with names similar to those used in the original MIB but with a "13" inserted to reference TLS 1.3.
2.2. Security Level

The RFC3411 architecture recognizes three levels of security:

* without authentication and without privacy (noAuthNoPriv)

* with authentication but without privacy (authNoPriv)

* with authentication and with privacy (authPriv)

With (D)TLS 1.3, authentication and privacy are always provided. Hence, all exchanges conforming to the rules of this document will include authentication and privacy, regardless of the security level requested.

// This is consistent with what was prescribed in RFC6353, where a // TLS Transport Model is expected to provide for outgoing // connections with a security level at least that of the requested // security level.

2.3. TLS Version

[RFC6353] stated that TLSTM clients and servers MUST NOT request, offer, or use SSL 2.0. This document extends this statement such that TLSTM clients and servers MUST NOT request, offer, or use SSL 3.0, (D)TLSv 1.0, (D)TLS v1.1. See Appendix D.5 of [RFC8446] for further details. For backward compatibility issues with older TLS versions, see Appendix D of [RFC8446].

An implementation that supports these older protocols is not considered conformant to the TLSTM while the older protocols are enabled.

2.4. SNMP Version

[RFC6353] stated that using a non-transport-aware Security Model with a secure Transport Model was not recommended. This document tightens this statement such that TLSTM clients and servers MUST NOT request, offer, or use SNMPv1 or SNMPv2c message processing described in [RFC3584], or the User-based Security Model of SNMPv3.

An implementation that supports these older protocols is not considered conformant to the TLSTM while the older protocols are enabled.
2.5. Common Name

[RFC6353] stated that the use of a certificate’s CommonName is deprecated and users were encouraged to use the subjectAltName. This document tightens this statement such that TLSTM clients and servers MUST NOT use the CommonName.

3. Additional Rules for TLS 1.3

This document specifies additional rules and clarifications for the use of TLS 1.3.

3.1. Zero Round Trip Time Resumption (0-RTT)

TLS 1.3 implementations for SNMPv3 MUST NOT enable the 0-RTT mode of session resumption (either sending or accepting) and MUST NOT automatically resend 0-RTT data if it is rejected by the server. The reason 0-RTT is disallowed is that there are no "safe" messages that if replayed will be guaranteed to cause no harm at a server side: all incoming notification or command responses are meant to be acted upon only once. See Security considerations section for further details.

TLS TM clients and servers MUST NOT request, offer or use the 0-RTT mode of TLS 1.3. [RFC8446] removed the renegotiation supported in TLS 1.2 [RFC5246]; for session resumption, it introduced a zero-RTT (0-RTT) mode, saving a round-trip at connection setup at the cost of increased risk of replay attacks (it is possible for servers to guard against this attack by keeping track of all the messages received). [RFC8446] requires a profile be written for any application that wants to use 0-RTT, specifying which messages are "safe to use" on this mode. The reason 0-RTT is disallowed here is that there are no "safe" SNMPv3 messages that if replayed will be sure to cause no harm at a server side: all incoming notification or command responses have consequences and are to be acted upon only once.

Renegotiation of sessions is not supported as it is not supported by TLS 1.3.

3.2. TLS ciphersuites, extensions and protocol invariants

[RFC8446] section 9 requires that, in the absence of application profiles, certain cipher suites, TLS extensions, and TLS protocol invariants are mandatory to implement. This document does not specify an application profile, hence all of the compliance requirements in [RFC8446] apply.

4. MIB Module Definition
SNMP-TLS-TM-MIB DEFINITIONS ::= BEGIN
IMPORTS
  MODULE-IDENTITY, OBJECT-TYPE,
  OBJECT-IDENTITY, mib-2, snmpDomains,
  Counter32, Unsigned32, Gauge32, NOTIFICATION-TYPE
  FROM SNMPv2-SMI   -- RFC 2578 or any update thereof
  TEXTUAL-CONVENTION, TimeStamp, RowStatus, StorageType,
  AutonomousType
  FROM SNMPv2-TC    -- RFC 2579 or any update thereof
  MODULE-COMPLIANCE, OBJECT-GROUP, NOTIFICATION-GROUP
  FROM SNMPv2-CONF  -- RFC 2580 or any update thereof
  SnmpAdminString
  FROM SNMP-FRAMEWORK-MIB  -- RFC 3411 or any update thereof
  snmpTargetParamsName, snmpTargetAddrName
  FROM SNMP-TARGET-MIB   -- RFC 3413 or any update thereof
;
nsmtpTlstmMIB MODULE-IDENTITY
LAST-UPDATED "202106220000Z"
ORGANIZATION "ISMS Working Group"
CONTACT-INFO "Kenneth Vaughn
  Trevilon LLC
  6606 FM 1488 RD, STE 503
  Magnolia, TX 77354
  USA
  kvaughn@trevilon.com"
DESCRIPTION "
  The TLS Transport Model MIB
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set forth in Section 4.c of the IETF Trust’s Legal Provisions
Relating to IETF Documents
(http://trustee.ietf.org/license-info)."
REVISION "202106220000Z"
DESCRIPTION "This version of this MIB module is part of
RFC XXXX; see the RFC itself for full legal
notices. This version updated the MIB to
support (D)TLS 1.3."

REVISION "201107190000Z"
DESCRIPTION "This version of this MIB module is part of
RFC 6353; see the RFC itself for full legal
notices. The only change was to introduce
new wording to reflect require changes for
IDNA addresses in the SnmpTLSAddress TC."
Internet-Draft      TLS 1.3 Transport Model for SNMP           June 2021

REVISION        "201005070000Z"
DESCRIPTION      "This version of this MIB module is part of
                 RFC 5953; see the RFC itself for full legal
                 notices."
 ::= { mib-2 198 }
-- **********************************************************************
-- subtrees of the SNMP-TLS-TM-MIB
-- **********************************************************************

snmpTlstmNotifications OBJECT IDENTIFIER ::= { snmpTlstmMIB 0 }

snmpTlstmIdentities OBJECT IDENTIFIER ::= { snmpTlstmMIB 1 }

snmpTlstmObjects OBJECT IDENTIFIER ::= { snmpTlstmMIB 2 }

snmpTlstmConformance OBJECT IDENTIFIER ::= { snmpTlstmMIB 3 }
-- **********************************************************************
-- snmpTlstmObjects - Objects
-- **********************************************************************

snmpTLSTCPDomain OBJECT-IDENTITY
STATUS      current
DESCRIPTION
"The SNMP over TLS via TCP transport domain. The corresponding
transport address is of type SnmpTLSAddress.
The securityName prefix to be associated with the
snmpTLSTCPDomain is 'tls'. This prefix may be used by
security models or other components to identify which secure
transport infrastructure authenticated a securityName."
REFERENCE
"RFC 2579: Textual Conventions for SMIv2"
 ::= { snmpDomains 8 }

snmpDTLSUDPDomain OBJECT-IDENTITY
STATUS      deprecated
DESCRIPTION
"The SNMP over DTLS via UDP transport domain. The corresponding
transport address is of type SnmpTLSAddress.
The securityName prefix to be associated with the
snmpDTLSUDPDomain is 'dtls'. This prefix may be used by
security models or other components to identify which secure
transport infrastructure authenticated a securityName."
REFERENCE
"RFC 2579: Textual Conventions for SMIv2"
 ::= { snmpDomains 9 }

SnmpTLSAddress ::= TEXTUAL-CONVENTION
DISPLAY-HINT "1a"
STATUS      current
DESCRIPTION
"Represents an IPv4 address, an IPv6 address, or a
US-ASCII-encoded hostname and port number.
An IPv4 address must be in dotted decimal format followed by a
colon ':' (US-ASCII character 0x3A) and a decimal port number
in US-ASCII."
An IPv6 address must be a colon-separated format (as described in RFC 5952), surrounded by square brackets ('[', US-ASCII character 0x5B, and ']'), US-ASCII character 0x5D), followed by a colon ':' (US-ASCII character 0x3A) and a decimal port number in US-ASCII.

A hostname is always in US-ASCII (as per RFC 1123); internationalized hostnames are encoded as A-labels as specified in RFC 5890. The hostname is followed by a colon ':' (US-ASCII character 0x3A) and a decimal port number in US-ASCII. The name SHOULD be fully qualified whenever possible.

Values of this textual convention may not be directly usable as transport-layer addressing information, and may require run-time resolution. As such, applications that write them must be prepared for handling errors if such values are not supported, or cannot be resolved (if resolution occurs at the time of the management operation).

The DESCRIPTION clause of TransportAddress objects that may have SnmpTLSAddress values must fully describe how (and when) such names are to be resolved to IP addresses and vice versa.

This textual convention SHOULD NOT be used directly in object definitions since it restricts addresses to a specific format. However, if it is used, it MAY be used either on its own or in conjunction with TransportAddressType or TransportDomain as a pair.

When this textual convention is used as a syntax of an index object, there may be issues with the limit of 128 sub-identifiers specified in SMIv2 (STD 58). It is RECOMMENDED that all MIB documents using this textual convention make explicit any limitations on index component lengths that management software must observe. This may be done either by including SIZE constraints on the index components or by specifying applicable constraints in the conceptual row DESCRIPTION clause or in the surrounding documentation.

REFERENCE

"RFC 1123: Requirements for Internet Hosts - Application and Support"
"RFC 5890: Internationalized Domain Names for Applications (IDNA): Definitions and Document Framework"
"RFC 5952: A Recommendation for IPv6 Address Text Representation"

SYNTAX OCTET STRING (SIZE (1..255))
SnmpTLSFingerprint ::= TEXTUAL-CONVENTION
DISPLAY-HINT "1x:1x"
STATUS deprecated
DESCRIPTION
"A fingerprint value that can be used to uniquely reference other data of potentially arbitrary length. An SnmpTLSFingerprint value is composed of a 1-octet hashing algorithm identifier followed by the fingerprint value. The octet value encoded is taken from the IANA TLS HashAlgorithm Registry (RFC 5246). The remaining octets are filled using the results of the hashing algorithm. This TEXTUAL-CONVENTION allows for a zero-length (blank) SnmpTLSFingerprint value for use in tables where the fingerprint value may be optional. MIB definitions or implementations may refuse to accept a zero-length value as appropriate. This textual convention was deprecated because TLS 1.3 uses a 2-octet cipher suite identifier rather than a 1-octet hashing algorithm identifier."

http://www.iana.org/assignments/tls-parameters/
"

SYNTAX OCTET STRING (SIZE (0..255))
SnmpTLS13Fingerprint ::= TEXTUAL-CONVENTION
DISPLAY-HINT "1x,1x"
STATUS       current
DESCRIPTION
"A fingerprint value that can be used to uniquely reference other data of potentially arbitrary length. An SnmpTLS13Fingerprint value is composed of a 2-octet cipher suite identifier followed by the fingerprint value. The octet value encoded is taken from the IANA TLS Cipher Suites Registry (RFC 8446). The remaining octets are filled using the results of the hashing algorithm, up to the first 253 octets. This TEXTUAL-CONVENTION allows for a zero-length (blank) SnmpTLS13Fingerprint value for use in tables where the fingerprint value may be optional. MIB definitions or implementations may refuse to accept a zero-length value as appropriate."

http://www.iana.org/assignments/tls-parameters/
"

SYNTAX OCTET STRING (SIZE (0..255))
-- Identities for use in the snmpTlstmCertToTSNTable and
-- snmpTlstmCertToTSN13Table
snmpTlstmCertToTSNMIdentities OBJECT IDENTIFIER
 ::= { snmpTlstmIdentities 1 }
status current
DESCRIPTION "Directly specifies the tmSecurityName to be used for
this certificate. The value of the tmSecurityName to use is specified in the snmpTlstmCertToTSN13Data column. The snmpTlstmCertToTSN13Data column must contain a non-zero length SnmpAdminString compliant value or the mapping described in this row must be considered a failure.

::= { snmpTlstmCertToTSNMIdentities 1 }

snmpTlstmCertSANRFC822Name OBJECT-IDENTITY
STATUS current
DESCRIPTION "Maps a subjectAltName’s rfc822Name to a tmSecurityName. The local part of the rfc822Name is passed unaltered but the host-part of the name must be passed in lowercase. This mapping results in a 1:1 correspondence between equivalent subjectAltName rfc822Name values and tmSecurityName values except that the host-part of the name MUST be passed in lowercase.
Example rfc822Name Field: FooBar@Example.COM is mapped to tmSecurityName: FooBar@example.com."

::= { snmpTlstmCertToTSNMIdentities 2 }

snmpTlstmCertSANDNSName OBJECT-IDENTITY
STATUS current
DESCRIPTION "Maps a subjectAltName’s dNSName to a tmSecurityName after first converting it to all lowercase (RFC 5280 does not specify converting to lowercase so this involves an extra step). This mapping results in a 1:1 correspondence between subjectAltName dNSName values and the tmSecurityName values."

::= { snmpTlstmCertToTSNMIdentities 3 }

snmpTlstmCertSANIpAddress OBJECT-IDENTITY
STATUS current
DESCRIPTION "Maps a subjectAltName’s IPAddress to a tmSecurityName by transforming the binary encoded address as follows:
1) for IPv4, the value is converted into a decimal-dotted quad address (e.g., ’192.0.2.1’).
2) for IPv6 addresses, the value is converted into a 32-character all lowercase hexadecimal string without any colon separators.
This mapping results in a 1:1 correspondence between subjectAltName IPAddress values and the tmSecurityName values.
The resulting length of an encoded IPv6 address is the maximum length supported by the View-Based
Access Control Model (VACM). Using both the Transport Security Model’s support for transport prefixes (see the SNMP-TSM-MIB’s snmpTsmConfigurationUsePrefix object for details) will result in securityName lengths that exceed what VACM can handle.

::= { snmpTlstmCertToTSNMIIdentities 4 }

<table>
<thead>
<tr>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>Maps any of the following fields using the corresponding mapping algorithms:</td>
</tr>
<tr>
<td>rfc822Name</td>
<td>snmpTlstmCertSANRFC822Name</td>
</tr>
<tr>
<td>dNSName</td>
<td>snmpTlstmCertSANDNSName</td>
</tr>
<tr>
<td>iPAddress</td>
<td>snmpTlstmCertSANIpAddress</td>
</tr>
</tbody>
</table>

The first matching subjectAltName value found in the certificate of the above types MUST be used when deriving the tmSecurityName. The mapping algorithm specified in the ‘Algorithm’ column MUST be used to derive the tmSecurityName. This mapping results in a 1:1 correspondence between subjectAltName values and tmSecurityName values. The three sub-mapping algorithms produced by this combined algorithm cannot produce conflicting results between themselves.

::= { snmpTlstmCertToTSNMIIdentities 5 }

<table>
<thead>
<tr>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>deprecated</td>
<td>Maps a certificate’s CommonName to a tmSecurityName after converting it to a UTF-8 encoding. The usage of CommonNames is deprecated and users are encouraged to use subjectAltName mapping methods instead. This mapping results in a 1:1 correspondence between certificate CommonName values and tmSecurityName values.</td>
</tr>
</tbody>
</table>

::= { snmpTlstmCertToTSNMIIdentities 6 }

-- The snmpTlstmSession Group

<table>
<thead>
<tr>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>The number of times an openSession() request has been executed</td>
</tr>
</tbody>
</table>
as a (D)TLS client, regardless of whether it succeeded or failed."
::= { snmpTlstmSession 1 }
snmpTlstmSessionClientCloses OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The number of times a closeSession() request has been
executed as a (D)TLS client, regardless of whether it
succeeded or failed."
::= { snmpTlstmSession 2 }
snmpTlstmSessionOpenErrors OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The number of times an openSession() request failed to open a
session as a (D)TLS client, for any reason."
::= { snmpTlstmSession 3 }
snmpTlstmSessionAccepts OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The number of times a (D)TLS server has accepted a new
connection from a client and has received at least one SNMP
message through it."
::= { snmpTlstmSession 4 }
snmpTlstmSessionServerCloses OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The number of times a closeSession() request has been
executed as a (D)TLS server, regardless of whether it
succeeded or failed."
::= { snmpTlstmSession 5 }
snmpTlstmSessionNoSessions OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The number of times an outgoing message was dropped because
the session associated with the passed tmStateReference was no
longer (or was never) available."
::= { snmpTlstmSession 6 }
snmpTlstmSessionInvalidClientCertificates OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION "The number of times an incoming session was not established on a (D)TLS server because the presented client certificate was invalid. Reasons for invalidation include, but are not limited to, cryptographic validation failures or lack of a suitable mapping row in the snmpTlstmCertToTSNTable or the snmpTlstmCertToTSN13Table."
::= { snmpTlstmSession 7 }

snmpTlstmSessionUnknownServerCertificate OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION "The number of times an outgoing session was not established on a (D)TLS client because the server certificate presented by an SNMP over (D)TLS server was invalid because no configured fingerprint or Certification Authority (CA) was acceptable to validate it. This may result because there was no entry in the snmpTlstmAddrTable (or snmpTlstmAddr13Table) or because no path could be found to a known CA."
::= { snmpTlstmSession 8 }

snmpTlstmSessionInvalidServerCertificates OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION "The number of times an outgoing session was not established on a (D)TLS client because the server certificate presented by an SNMP over (D)TLS server could not be validated even if the fingerprint or expected validation path was known. That is, a cryptographic validation error occurred during certificate validation processing. Reasons for invalidation include, but are not limited to, cryptographic validation failures."
::= { snmpTlstmSession 9 }

snmpTlstmSessionInvalidCaches OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION "The number of outgoing messages dropped because the tmStateReference referred to an invalid cache."
::= { snmpTlstmSession 10 }
-- Configuration Objects
snmpTlstmConfig OBJECT IDENTIFIER ::= {snmpTlstmObjects 2}

-- Certificate mapping
snmpTlstmCertificateMapping OBJECT IDENTIFIER ::= {snmpTlstmConfig 1}

snmpTlstmCertToTSNCount OBJECT-TYPE
SYNTAX         Gauge32
MAX-ACCESS     read-only
STATUS         deprecated
DESCRIPTION    "A count of the number of entries in the
snmpTlstmCertToTSNTable."
::= { snmpTlstmCertificateMapping 1 }

snmpTlstmCertToTSNTableLastChanged OBJECT-TYPE
SYNTAX         TimeStamp
MAX-ACCESS     read-only
STATUS         deprecated
DESCRIPTION    "The value of sysUpTime.0 when the snmpTlstmCertToTSNTable was
last modified through any means, or 0 if it has not been
modified since the command responder was started."
::= { snmpTlstmCertificateMapping 2 }

snmpTlstmCertToTSNTable OBJECT-TYPE
SYNTAX         SEQUENCE OF SnmpTlstmCertToTSNEntry
MAX-ACCESS     not-accessible
STATUS         deprecated
DESCRIPTION    "This table is used by a (D)TLS server to map the (D)TLS
client’s presented X.509 certificate to a tmSecurityName.
On an incoming (D)TLS/SNMP connection, the client’s presented
certificate must either be validated based on an established
trust anchor, or it must directly match a fingerprint in this
table. This table does not provide any mechanisms for
configuring the trust anchors; the transfer of any needed
trusted certificates for path validation is expected to occur
through an out-of-band transfer.
Once the certificate has been found acceptable (either by path
validation or directly matching a fingerprint in this table),
this table is consulted to determine the appropriate
tmSecurityName to identify with the remote connection. This
is done by considering each active row from this table in
prioritized order according to its snmpTlstmCertToTSNID value.
Each row’s snmpTlstmCertToTSNFingerprint value determines
whether the row is a match for the incoming connection:
1) If the row’s snmpTlstmCertToTSNFingerprint value
identifies the presented certificate, then consider the
row as a successful match.
2) If the row’s snmpTlstmCertToTSNFingerprint value
identifies a locally held copy of a trusted CA
certificate and that CA certificate was used to validate the path to the presented certificate, then consider the row as a successful match.

Once a matching row has been found, the snmpTlstmCertToTSNMapType value can be used to determine how the tmSecurityName to associate with the session should be determined. See the snmpTlstmCertToTSNMapType column’s DESCRIPTION for details on determining the tmSecurityName value. If it is impossible to determine a tmSecurityName from the row’s data combined with the data presented in the certificate, then additional rows MUST be searched looking for another potential match. If a resulting tmSecurityName mapped from a given row is not compatible with the needed requirements of a tmSecurityName (e.g., VACM imposes a 32-octet-maximum length and the certificate derived securityName could be longer), then it must be considered an invalid match and additional rows MUST be searched looking for another potential match.

If no matching and valid row can be found, the connection MUST be closed and SNMP messages MUST NOT be accepted over it.

Missing values of snmpTlstmCertToTSNID are acceptable and implementations should continue to the next highest numbered row. It is recommended that administrators skip index values to leave room for the insertion of future rows (for example, use values of 10 and 20 when creating initial rows).

Users are encouraged to make use of certificates with subjectAltName fields that can be used as tmSecurityNames so that a single root CA certificate can allow all child certificate’s subjectAltName to map directly to a tmSecurityName via a 1:1 transformation. However, this table is flexible to allow for situations where existing deployed certificate infrastructures do not provide adequate subjectAltName values for use as tmSecurityNames. Direct mapping from each individual certificate fingerprint to a tmSecurityName is also possible but requires one entry in the table per tmSecurityName and requires more management operations to completely configure a device.

This table and its associated objects were deprecated because the fingerprint format changed to support TLS 1.3. By deprecating (and creating an updated) table, rather than just the fingerprint object, an implementation is able to support both the original TLS and new TLS 1.3 tables while forcing some agents to only use TLS 1.3."

::= { snmpTlstmCertificateMapping 3 }

snmpTlstmCertToTSNEntry OBJECT-TYPE
SYNTAX SnmpTlstmCertToTSNEntry
MAX-ACCESS not-accessible
A row in the snmpTlstmCertToTSNTable that specifies a mapping for an incoming (D)TLS certificate to a tmSecurityName to use for a connection.

INDEX { snmpTlstmCertToTSNID }
 ::= { snmpTlstmCertToTSNTable 1 }

SnmpTlstmCertToTSNEntry ::= SEQUENCE {
  snmpTlstmCertToTSNID           Unsigned32,
  snmpTlstmCertToTSNFingerprint  SnmpTLSFingerprint,
  snmpTlstmCertToTSNMapType      AutonomousType,
  snmpTlstmCertToTSNData         OCTET STRING,
  snmpTlstmCertToTSNStorageType  StorageType,
  snmpTlstmCertToTSNRowStatus    RowStatus
}

snmpTlstmCertToTSNID OBJECT-TYPE
SYNTAX      Unsigned32 (1..4294967295)
MAX-ACCESS  not-accessible
STATUS      deprecated
DESCRIPTION  "A unique, prioritized index for the given entry. Lower numbers indicate a higher priority."
 ::= { snmpTlstmCertToTSNEntry 1 }

snmpTlstmCertToTSNFingerprint OBJECT-TYPE
SYNTAX      SnmpTLSFingerprint (SIZE(1..255))
MAX-ACCESS  read-create
STATUS      deprecated
DESCRIPTION  "A cryptographic hash of an X.509 certificate. The results of a successful matching fingerprint to either the trusted CA in the certificate validation path or to the certificate itself is dictated by the snmpTlstmCertToTSNMapType column. This object was deprecated because TLS 1.3 uses a 2-octet cipher suite identifier rather than a 1-octet hashing algorithm identifier."
 ::= { snmpTlstmCertToTSNEntry 2 }

snmpTlstmCertToTSNMapType OBJECT-TYPE
SYNTAX      AutonomousType
MAX-ACCESS  read-create
STATUS      deprecated
DESCRIPTION  "Specifies the mapping type for deriving a tmSecurityName from a certificate. Details for mapping of a particular type SHALL be specified in the DESCRIPTION clause of the OBJECT-IDENTITY that describes the mapping. If a mapping succeeds it will return a tmSecurityName for use by the TLSTM model and processing stops.
If the resulting mapped value is not compatible with the
needed requirements of a tmSecurityName (e.g., VACM imposes a
32-octet-maximum length and the certificate derived
securityName could be longer), then future rows MUST be
searched for additional snmpTlstmCertToTSNfingerprint matches
to look for a mapping that succeeds.
Suitable values for assigning to this object that are defined
within the SNMP-TLS-TM-MIB can be found in the
snmpTlstmCertToTSNIdentities portion of the MIB tree.

DEFVAL { snmpTlstmCertSpecified }
::= { snmpTlstmCertToTSNEntry 3 }

snmpTlstmCertToTSNData OBJECT-TYPE
SYNTAX      OCTET STRING (SIZE(0..1024))
MAX-ACCESS  read-create
STATUS      deprecated
DESCRIPTION
"Auxiliary data used as optional configuration information for
a given mapping specified by the snmpTlstmCertToTSNmapType
column. Only some mapping systems will make use of this
column. The value in this column MUST be ignored for any
mapping type that does not require data present in this
column."

DEFVAL { "" }
::= { snmpTlstmCertToTSNEntry 4 }

snmpTlstmCertToTSNStorageType OBJECT-TYPE
SYNTAX      StorageType
MAX-ACCESS  read-create
STATUS      deprecated
DESCRIPTION
"The storage type for this conceptual row. Conceptual rows
having the value 'permanent' need not allow write-access to
any columnar objects in the row."

DEFVAL { nonVolatile }
::= { snmpTlstmCertToTSNEntry 5 }

snmpTlstmCertToTSNRowStatus OBJECT-TYPE
SYNTAX      RowStatus
MAX-ACCESS  read-create
STATUS      deprecated
DESCRIPTION
"The status of this conceptual row. This object may be used
to create or remove rows from this table.
To create a row in this table, an administrator must set this
object to either createAndGo(4) or createAndWait(5).
Until instances of all corresponding columns are appropriately
configured, the value of the corresponding instance of the
snmpTlstmParamsRowStatus column is notReady(3).
In particular, a newly created row cannot be made active until
the corresponding snmpTlstmCertToTSNfingerprint,
snmpTlstmCertToTSNmapType, and snmpTlstmCertToTSNData columns
have been set.
The following objects may not be modified while the
value of this object is active(1):
   - snmpTlstmCertToTSNFingerprint
   - snmpTlstmCertToTSNMapType
   - snmpTlstmCertToTSNData
An attempt to set these objects while the value of
snmpTlstmParamsRowStatus is active(1) will result in
an inconsistentValue error.

::= { snmpTlstmCertToTSNEntry 6 }

-- Maps tmSecurityNames to certificates for use by SNMP-TARGET-MIB

snmpTlstmParamsCount OBJECT-TYPE
SYNTAX      Gauge32
MAX-ACCESS  read-only
STATUS      deprecated
DESCRIPTION
   "A count of the number of entries in the snmpTlstmParamsTable."
::= { snmpTlstmCertificateMapping 4 }

snmpTlstmParamsTableLastChanged OBJECT-TYPE
SYNTAX      TimeStamp
MAX-ACCESS  read-only
STATUS      deprecated
DESCRIPTION
   "The value of sysUpTime.0 when the snmpTlstmParamsTable
    was last modified through any means, or 0 if it has not been
    modified since the command responder was started."
::= { snmpTlstmCertificateMapping 5 }

snmpTlstmParamsTable OBJECT-TYPE
SYNTAX      SEQUENCE OF SnmpTlstmParamsEntry
MAX-ACCESS  not-accessible
STATUS      deprecated
DESCRIPTION
   "This table is used by a (D)TLS client when a (D)TLS
    connection is being set up using an entry in the
    SNMP-TARGET-MIB. It extends the SNMP-TARGET-MIB’s
    snmpTargetParamsTable with a fingerprint of a certificate to
    use when establishing such a (D)TLS connection."
::= { snmpTlstmCertificateMapping 6 }

snmpTlstmParamsEntry OBJECT-TYPE
SYNTAX       SnmpTlstmParamsEntry
MAX-ACCESS   not-accessible
STATUS       deprecated
DESCRIPTION
   "A conceptual row containing a fingerprint hash of a locally
    held certificate for a given snmpTargetParamsEntry. The
    values in this row should be ignored if the connection that
    needs to be established, as indicated by the SNMP-TARGET-MIB
    infrastructure, is not a certificate and TLS based
connection. The connection SHOULD NOT be established if the
certificate fingerprint stored in this entry does not point to
a valid locally held certificate or if it points to an
unusable certificate (such as might happen when the
certificate’s expiration date has been reached)."

INDEX  { IMPLIED snmpTargetParamsName } ::= { snmpTlstmParamsTable 1 }
SnmpTlstmParamsEntry ::= SEQUENCE {
  snmpTlstmParamsClientFingerprint SnmpTLSFingerprint,
  snmpTlstmParamsStorageType       StorageType,
  snmpTlstmParamsRowStatus         RowStatus
}

SnmpTlstmParamsClientFingerprint OBJECT-TYPE
SYNTAX      SnmpTLSFingerprint
MAX-ACCESS  read-create
STATUS       deprecated
DESCRIPTION  "This object stores the hash of the public portion of a
locally held X.509 certificate. The X.509 certificate, its
public key, and the corresponding private key will be used
when initiating a TLS connection as a TLS client."
::= { snmpTlstmParamsEntry 1 }

SnmpTlstmParamsStorageType OBJECT-TYPE
SYNTAX      StorageType
MAX-ACCESS  read-create
STATUS       deprecated
DESCRIPTION  "The storage type for this conceptual row. Conceptual rows
having the value 'permanent' need not allow write-access to
any columnar objects in the row."
DEFVAL      { nonVolatile }
::= { snmpTlstmParamsEntry 2 }

SnmpTlstmParamsRowStatus OBJECT-TYPE
SYNTAX      RowStatus
MAX-ACCESS  read-create
STATUS       deprecated
DESCRIPTION  "The status of this conceptual row. This object may be used
to create or remove rows from this table.
To create a row in this table, an administrator must set this
object to either createAndGo(4) or createAndWait(5).
Until instances of all corresponding columns are appropriately
configured, the value of the corresponding instance of the
snmpTlstmParamsRowStatus column is notReady(3).
In particular, a newly created row cannot be made active until
the corresponding snmpTlstmParamsClientFingerprint column has
been set.
The snmpTlstmParamsClientFingerprint object may not be modified
while the value of this object is active(1).
An attempt to set these objects while the value of
snmpTlstmParamsRowStatus is active(1) will result in
an inconsistentValue error.

```::= { snmpTlstmParamsEntry 3 }
```

mpTlstmAddrCount OBJECT-TYPE
SYNTAX Gauge32
MAX-ACCESS read-only
STATUS deprecated
DESCRIPTION
"A count of the number of entries in the snmpTlstmAddrTable."

```::= { snmpTlstmCertificateMapping 7 }
```

snmpTlstmAddrTableLastChanged OBJECT-TYPE
SYNTAX TimeStamp
MAX-ACCESS read-only
STATUS deprecated
DESCRIPTION
"The value of sysUpTime.0 when the snmpTlstmAddrTable
was last modified through any means, or 0 if it has not been
modified since the command responder was started."

```::= { snmpTlstmCertificateMapping 8 }
```

snmpTlstmAddrTable OBJECT-TYPE
SYNTAX SEQUENCE OF SnmpTlstmAddrEntry
MAX-ACCESS not-accessible
STATUS deprecated
DESCRIPTION
"This table is used by a TLS client when a TLS
connection is being set up using an entry in the
SNMP-TARGET-MIB. It extends the SNMP-TARGET-MIB’s
snmpTargetAddrTable so that the client can verify that the
correct server has been reached. This verification can use
either a certificate fingerprint, or an identity
authenticated via certification path validation.
If there is an active row in this table corresponding to the
entry in the SNMP-TARGET-MIB that was used to establish the
connection, and the row’s snmpTlstmAddrServerFingerprint
column has non-empty value, then the server’s presented
certificate is compared with the
snmpTlstmAddrServerFingerprint value (and the
snmpTlstmAddrServerIdentity column is ignored). If the
fingerprint matches, the verification has succeeded. If the
fingerprint does not match, then the connection MUST be
closed.
If the server’s presented certificate has passed
certification path validation [RFC5280] to a configured
trust anchor, and an active row exists with a zero-length
snmpTlstmAddrServerFingerprint value, then the
snmpTlstmAddrServerIdentity column contains the expected
host name. This expected host name is then compared against
the server’s certificate as follows:
- Implementations MUST support matching the expected host
  name against a dNSName in the subjectAltName extension
  field
- The '*' (ASCII 0x2a) wildcard character is allowed in the
dNSName of the subjectAltName extension, but only as the
left-most (least significant) DNS label in that value.
This wildcard matches any left-most DNS label in the
server name. That is, the subject *.example.com matches
the server names a.example.com and b.example.com, but does
not match example.com or a.b.example.com. Implementations
MUST support wildcards in certificates as specified above,
but MAY provide a configuration option to disable them.
- If the locally configured name is an internationalized
domain name, conforming implementations MUST convert it to
the ASCII Compatible Encoding (ACE) format for performing
comparisons, as specified in Section 7 of [RFC5280].
If the expected host name fails these conditions then the
connection MUST be closed.

If there is no row in this table corresponding to the entry
in the SNMP-TARGET-MIB and the server can be authorized by
another, implementation-dependent means, then the connection
MAY still proceed.

::= { snmpTlstmCertificateMapping 9 }

snmpTlstmAddrEntry OBJECT-TYPE
SYNTAX            SnmpTlstmAddrEntry
MAX-ACCESS        not-accessible
STATUS            deprecated
DESCRIPTION
"A conceptual row containing a copy of a certificate’s
fingerprint for a given snmpTargetAddrEntry. The values in
this row should be ignored if the connection that needs to be
established, as indicated by the SNMP-TARGET-MIB
infrastructure, is not a TLS based connection. If an
snmpTlstmAddrEntry exists for a given snmpTargetAddrEntry, then
the presented server certificate MUST match or the connection
MUST NOT be established. If a row in this table does not
exist to match an snmpTargetAddrEntry row, then the connection
SHOULD still proceed if some other certificate validation path
algorithm (e.g., RFC 5280) can be used."

INDEX             { IMPLIED snmpTargetAddrName }
 ::= { snmpTlstmAddrTable 1 }
SnmpTlstmAddrEntry ::= SEQUENCE {
  snmpTlstmAddrServerFingerprint    SnmpTLSFingerprint,
  snmpTlstmAddrServerIdentity       SnmpAdminString,
  snmpTlstmAddrStorageType          StorageType,
snmpTlstmAddrRowStatus RowStatus
}
snmpTlstmAddrServerFingerprint OBJECT-TYPE
SYNTAX SnmpTLSFingerprint
MAX-ACCESS read-create
STATUS deprecated
DESCRIPTION
"A cryptographic hash of a public X.509 certificate. This object should store the hash of the public X.509 certificate that the remote server should present during the TLS connection setup. The fingerprint of the presented certificate and this hash value MUST match exactly or the connection MUST NOT be established."
DEFVAL { "" }
::= { snmpTlstmAddrEntry 1 }
snmpTlstmAddrServerIdentity OBJECT-TYPE
SYNTAX SnmpAdminString
MAX-ACCESS read-create
STATUS deprecated
DESCRIPTION
"The reference identity to check against the identity presented by the remote system."
DEFVAL { "" }
::= { snmpTlstmAddrEntry 2 }
snmpTlstmAddrStorageType OBJECT-TYPE
SYNTAX StorageType
MAX-ACCESS read-create
STATUS deprecated
DESCRIPTION
"The storage type for this conceptual row. Conceptual rows having the value 'permanent' need not allow write-access to any columnar objects in the row."
DEFVAL { nonVolatile }
::= { snmpTlstmAddrEntry 3 }
snmpTlstmAddrRowStatus OBJECT-TYPE
SYNTAX RowStatus
MAX-ACCESS read-create
STATUS deprecated
DESCRIPTION
"The status of this conceptual row. This object may be used to create or remove rows from this table. To create a row in this table, an administrator must set this object to either createAndGo(4) or createAndWait(5). Until instances of all corresponding columns are appropriately configured, the value of the corresponding instance of the snmpTlstmAddrRowStatus column is notReady(3). In particular, a newly created row cannot be made active until
the corresponding snmpTlstmAddrServerFingerprint column has been set. Rows MUST NOT be active if the snmpTlstmAddrServerFingerprint column is blank and the snmpTlstmAddrServerIdentity is set to "" since this would insecurely accept any presented certificate.

The snmpTlstmAddrServerFingerprint object may not be modified while the value of this object is active(1). An attempt to set these objects while the value of snmpTlstmAddrRowStatus is active(1) will result in an inconsistentValue error.

::= { snmpTlstmAddrRowEntry 4 }

snmpTlstmCertToTSN13Count OBJECT-TYPE
SYNTAX Gauge32
MAX-ACCESS read-only
STATUS current
DESCRIPTION "A count of the number of entries in the snmpTlstmCertToTSN13Table."
::= { snmpTlstmCertificateMapping 10 }

snmpTlstmCertToTSN13TableLastChanged OBJECT-TYPE
SYNTAX TimeStamp
MAX-ACCESS read-only
STATUS current
DESCRIPTION "The value of sysUpTime.0 when the snmpTlstmCertToTSN13Table was last modified through any means, or 0 if it has not been modified since the command responder was started."
::= { snmpTlstmCertificateMapping 11 }

snmpTlstmCertToTSN13Table OBJECT-TYPE
SYNTAX SEQUENCE OF SnmpTlstmCertToTSN13Entry
MAX-ACCESS not-accessible
STATUS current
DESCRIPTION "This table is used by a TLS 1.3 server to map the TLS 1.3 client’s presented X.509 certificate to a tmSecurityName. On an incoming TLS/SNMP connection, the client’s presented certificate must either be validated based on an established trust anchor, or it must directly match a fingerprint in this table. This table does not provide any mechanisms for configuring the trust anchors; the transfer of any needed trusted certificates for path validation is expected to occur through an out-of-band transfer. Once the certificate has been found acceptable (either by path validation or directly matching a fingerprint in this table), this table is consulted to determine the appropriate tmSecurityName to identify with the remote connection. This
is done by considering each active row from this table in prioritized order according to its snmpTlstmCertToTSN13ID value. Each row’s snmpTlstmCertToTSN13Fingerprint value determines whether the row is a match for the incoming connection:

1) If the row’s snmpTlstmCertToTSN13Fingerprint value identifies the presented certificate, then consider the row as a successful match.
2) If the row’s snmpTlstmCertToTSN13Fingerprint value identifies a locally held copy of a trusted CA certificate and that CA certificate was used to validate the path to the presented certificate, then consider the row as a successful match.

Once a matching row has been found, the snmpTlstmCertToTSN13MapType value can be used to determine how the tmSecurityName to associate with the session should be determined. See the snmpTlstmCertToTSN13MapType column’s DESCRIPTION for details on determining the tmSecurityName value. If it is impossible to determine a tmSecurityName from the row’s data combined with the data presented in the certificate, then additional rows MUST be searched looking for another potential match. If a resulting tmSecurityName mapped from a given row is not compatible with the needed requirements of a tmSecurityName (e.g., VACM imposes a 32-octet-maximum length and the certificate derived securityName could be longer), then it must be considered an invalid match and additional rows MUST be searched looking for another potential match.

If no matching and valid row can be found, the connection MUST be closed and SNMP messages MUST NOT be accepted over it. Missing values of snmpTlstmCertToTSN13ID are acceptable and implementations should continue to the next highest numbered row. It is recommended that administrators skip index values to leave room for the insertion of future rows (for example, use values of 10 and 20 when creating initial rows).

Users are encouraged to make use of certificates with subjectAltName fields that can be used as tmSecurityNames so that a single root CA certificate can allow all child certificate’s subjectAltName to map directly to a tmSecurityName via a 1:1 transformation. However, this table is flexible to allow for situations where existing deployed certificate infrastructures do not provide adequate subjectAltName values for use as tmSecurityNames. Direct mapping from each individual certificate fingerprint to a tmSecurityName is possible but requires one entry in the table per tmSecurityName and requires more management operations to completely configure a device.

::= { snmpTlstmCertificateMapping 12 }
snmpTlstmCertToTSN13Entry OBJECT-TYPE
SYNTAX       SnmpTlstmCertToTSN13Entry
MAX-ACCESS   not-accessible
STATUS       current
DESCRIPTION  "A row in the snmpTlstmCertToTSN13Table that specifies a
mapping for an incoming TLS certificate to a tmSecurityName
to use for a connection."
INDEX   { snmpTlstmCertToTSN13ID }
::= { snmpTlstmCertToTSN13Table 1 }
SnmpTlstmCertToTSN13Entry ::= SEQUENCE {
  snmpTlstmCertToTSN13ID           Unsigned32,
  snmpTlstmCertToTSN13Fingerprint  SnmpTLS13Fingerprint,
  snmpTlstmCertToTSN13MapType      AutonomousType,
  snmpTlstmCertToTSN13Data         OCTET STRING,
  snmpTlstmCertToTSN13StorageType  StorageType,
  snmpTlstmCertToTSN13RowStatus    RowStatus
}

snmpTlstmCertToTSN13ID OBJECT-TYPE
SYNTAX       Unsigned32 (1..4294967295)
MAX-ACCESS   not-accessible
STATUS       current
DESCRIPTION  "A unique, prioritized index for the given entry. Lower
numbers indicate a higher priority."
::= { snmpTlstmCertToTSN13Entry 1 }

snmpTlstmCertToTSN13Fingerprint OBJECT-TYPE
SYNTAX       SnmpTLS13Fingerprint (SIZE(2..255))
MAX-ACCESS   read-create
STATUS       current
DESCRIPTION  "A cryptographic hash of an X.509 certificate. The results of
a successful matching fingerprint to either the trusted CA in
the certificate validation path or to the certificate itself
is dictated by the snmpTlstmCertToTSN13MapType column."
::= { snmpTlstmCertToTSN13Entry 2 }

snmpTlstmCertToTSN13MapType OBJECT-TYPE
SYNTAX       AutonomousType
MAX-ACCESS   read-create
STATUS       current
DESCRIPTION  "Specifies the mapping type for deriving a tmSecurityName from
a certificate. Details for mapping of a particular type SHALL
be specified in the DESCRIPTION clause of the OBJECT-IDENTITY
that describes the mapping. If a mapping succeeds it will
return a tmSecurityName for use by the TLSTM model and
processing stops.
If the resulting mapped value is not compatible with the
needed requirements of a tmSecurityName (e.g., VACM imposes a 32-octet-maximum length and the certificate derived securityName could be longer), then future rows MUST be searched for additional snmpTlstmCertToTSN13Fingerprint matches to look for a mapping that succeeds.

Suitable values for assigning to this object that are defined within the SNMP-TLS-TM-MIB can be found in the snmpTlstmCertToTSN13Identities portion of the MIB tree.

DEFVAL { snmpTlstmCertSpecified } ::= { snmpTlstmCertToTSN13Entry 3 }

snmpTlstmCertToTSN13Data OBJECT-TYPE
SYNTAX OCTET STRING (SIZE(0..1024))
MAX-ACCESS read-create
STATUS current
DESCRIPTION "Auxiliary data used as optional configuration information for a given mapping specified by the snmpTlstmCertToTSN13MapType column. Only some mapping systems will make use of this column. The value in this column MUST be ignored for any mapping type that does not require data present in this column."

DEFVAL { "" }
 ::= { snmpTlstmCertToTSN13Entry 4 }

snmpTlstmCertToTSN13StorageType OBJECT-TYPE
SYNTAX StorageType
MAX-ACCESS read-create
STATUS current
DESCRIPTION "The storage type for this conceptual row. Conceptual rows having the value ‘permanent’ need not allow write-access to any columnar objects in the row."

DEFVAL { nonVolatile } ::= { snmpTlstmCertToTSN13Entry 5 }

snmpTlstmCertToTSN13RowStatus OBJECT-TYPE
SYNTAX RowStatus
MAX-ACCESS read-create
STATUS current
DESCRIPTION "The status of this conceptual row. This object may be used to create or remove rows from this table. To create a row in this table, an administrator must set this object to either createAndGo(4) or createAndWait(5). Until instances of all corresponding columns are appropriately configured, the value of the corresponding instance of the snmpTlstmParams13RowStatus column is notReady(3). In particular, a newly created row cannot be made active until the corresponding snmpTlstmCertToTSN13Fingerprint, snmpTlstmCertToTSN13MapType, and snmpTlstmCertToTSN13Data
columns have been set.
The following objects may not be modified while the
value of this object is active(1):
- snmpTlstmCertToTSN13Fingerprint
- snmpTlstmCertToTSN13MapType
- snmpTlstmCertToTSN13Data
An attempt to set these objects while the value of
snmpTlstmParams13RowStatus is active(1) will result in
an inconsistentValue error.

::= { snmpTlstmCertToTSN13Entry 6 }

snmpTlstmParams13Count OBJECT-TYPE
SYNTAX      Gauge32
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
  "A count of the number of entries in the
  snmpTlstmParams13Table."
::= { snmpTlstmCertificateMapping 13 }

snmpTlstmParams13TableLastChanged OBJECT-TYPE
SYNTAX      TimeStamp
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
  "The value of sysUpTime.0 when the snmpTlstmParams13Table
  was last modified through any means, or 0 if it has not been
  modified since the command responder was started."
::= { snmpTlstmCertificateMapping 14 }

snmpTlstmParams13Table OBJECT-TYPE
SYNTAX      SEQUENCE OF SnmpTlstmParams13Entry
MAX-ACCESS not-accessible
STATUS      current
DESCRIPTION
  "This table is used by a TLS client when a TLS
  connection is being set up using an entry in the
  SNMP-TARGET-MIB. It extends the SNMP-TARGET-MIB's
  snmpTargetParams13Table with a fingerprint of a certificate to
  use when establishing such a TLS connection."
::= { snmpTlstmCertificateMapping 15 }

snmpTlstmParams13Entry OBJECT-TYPE
SYNTAX      SnmpTlstmParams13Entry
MAX-ACCESS not-accessible
STATUS      current
DESCRIPTION
  "A conceptual row containing a fingerprint hash of a locally
  held certificate for a given snmpTargetParamsEntry. The
  values in this row should be ignored if the connection that
  needs to be established, as indicated by the SNMP-TARGET-MIB
  infrastructure, is not a certificate and TLS based
connection. The connection SHOULD NOT be established if the
certificate fingerprint stored in this entry does not point to
a valid locally held certificate or if it points to an
unusable certificate (such as might happen when the
certificate’s expiration date has been reached)."

INDEX    { IMPLIED snmpTargetParamsName }
::= { snmpTlstmParams13Table 1 }
SnmpTlstmParams13Entry ::= SEQUENCE {
   snmpTlstmParams13ClientFingerprint SnmpTLS13Fingerprint,
   snmpTlstmParams13StorageType       StorageType,
   snmpTlstmParams13RowStatus         RowStatus
}

SnmpTlstmParams13ClientFingerprint OBJECT-TYPE
SYNTAX      SnmpTLS13Fingerprint
MAX-ACCESS  read-create
STATUS      current
DESCRIPTION
"This object stores the hash of the public portion of a
locally held X.509 certificate. The X.509 certificate, its
public key, and the corresponding private key will be used
when initiating a TLS connection as a TLS client."
::= { snmpTlstmParams13Entry 1 }

SnmpTlstmParams13StorageType OBJECT-TYPE
SYNTAX      StorageType
MAX-ACCESS  read-create
STATUS      current
DESCRIPTION
"The storage type for this conceptual row. Conceptual rows
having the value ‘permanent’ need not allow write-access to
any columnar objects in the row."
DEFVAL      { nonVolatile }
::= { snmpTlstmParams13Entry 2 }

SnmpTlstmParams13RowStatus OBJECT-TYPE
SYNTAX      RowStatus
MAX-ACCESS  read-create
STATUS      current
DESCRIPTION
"The status of this conceptual row. This object may be used
to create or remove rows from this table.
To create a row in this table, an administrator must set this
object to either createAndGo(4) or createAndWait(5).
Until instances of all corresponding columns are appropriately
configured, the value of the corresponding instance of the
snmpTlstmParams13RowStatus column is notReady(3).
In particular, a newly created row cannot be made active until
the corresponding snmpTlstmParams13ClientFingerprint column has
been set.
The snmpTlstmParams13ClientFingerprint object may not be
modified while the value of this object is active(1).
An attempt to set these objects while the value of
snmpTlstmParams13RowStatus is active(1) will result in
an inconsistentValue error."
::= { snmpTlstmParams13Entry 3 }

snmpTlstmAddr13Count OBJECT-TYPE
SYNTAX      Gauge32
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"A count of the number of entries in the snmpTlstmAddr13Table."
::= { snmpTlstmCertificateMapping 16 }

snmpTlstmAddr13TableLastChanged OBJECT-TYPE
SYNTAX      TimeStamp
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"The value of sysUpTime.0 when the snmpTlstmAddr13Table
was last modified through any means, or 0 if it has not been
modified since the command responder was started."
::= { snmpTlstmCertificateMapping 17 }

snmpTlstmAddr13Table OBJECT-TYPE
SYNTAX      SEQUENCE OF SnmpTlstmAddr13Entry
MAX-ACCESS  not-accessible
STATUS      current
DESCRIPTION
"This table is used by a TLS client when a TLS
connection is being set up using an entry in the
SNMP-TARGET-MIB. It extends the SNMP-TARGET-MIB’s
snmpTargetAddrTable so that the client can verify that the
correct server has been reached. This verification can use
either a certificate fingerprint, or an identity
authenticated via certification path validation.
If there is an active row in this table corresponding to the
entry in the SNMP-TARGET-MIB that was used to establish the
connection, and the row’s snmpTlstmAddr13ServerFingerprint
column has non-empty value, then the server’s presented
certificate is compared with the
snmpTlstmAddr13ServerFingerprint value (and the
snmpTlstmAddr13ServerIdentity column is ignored). If the
fingerprint matches, the verification has succeeded. If the
fingerprint does not match, then the connection MUST be
closed.
If the server’s presented certificate has passed
certification path validation [RFC5280] to a configured
trust anchor, and an active row exists with a zero-length
snmpTlstmAddr13ServerFingerprint value, then the
snmpTlstmAddr13ServerIdentity column contains the expected
host name. This expected host name is then compared against the server’s certificate as follows:
- Implementations MUST support matching the expected host name against a dNSName in the subjectAltName extension field.
- The ‘*’ (ASCII 0x2a) wildcard character is allowed in the dNSName of the subjectAltName extension, but only as the left-most (least significant) DNS label in that value. This wildcard matches any left-most DNS label in the server name. That is, the subject *.example.com matches the server names a.example.com and b.example.com, but does not match example.com or a.b.example.com. Implementations MUST support wildcards in certificates as specified above, but MAY provide a configuration option to disable them.
- If the locally configured name is an internationalized domain name, conforming implementations MUST convert it to the ASCII Compatible Encoding (ACE) format for performing comparisons, as specified in Section 7 of [RFC5280].
If the expected host name fails these conditions then the connection MUST be closed.

If there is no row in this table corresponding to the entry in the SNMP-TARGET-MIB and the server can be authorized by another, implementation-dependent means, then the connection MAY still proceed.

::= { snmpTlstmCertificateMapping 18 }

SnmpTlstmAddr13Entry OBJECT-TYPE
SYNTAX SnmpTlstmAddr13Entry
MAX-ACCESS not-accessible
STATUS current
DESCRIPTION "A conceptual row containing a copy of a certificate’s fingerprint for a given snmpTargetAddrEntry. The values in this row should be ignored if the connection that needs to be established, as indicated by the SNMP-TARGET-MIB infrastructure, is not a TLS based connection. If an snmpTlstmAddr13Entry exists for a given snmpTargetAddrEntry, then the presented server certificate MUST match or the connection MUST NOT be established. If a row in this table does not exist to match an snmpTargetAddrEntry row, then the connection SHOULD still proceed if some other certificate validation path algorithm (e.g., RFC 5280) can be used."
INDEX { IMPLIED snmpTargetAddrName }
::= { snmpTlstmAddr13Table 1 }

SnmpTlstmAddr13Entry ::= SEQUENCE {
    snmpTlstmAddr13ServerFingerprint SnmpTLS13Fingerprint,
    snmpTlstmAddr13ServerIdentity SnmpAdminString,
    snmpTlstmAddr13StorageType StorageType,
snmpTlstmAddr13RowStatus RowStatus
}

snmpTlstmAddr13ServerFingerprint OBJECT-TYPE
SYNTAX      SnmpTLS13Fingerprint
MAX-ACCESS  read-create
STATUS      current
DESCRIPTION
  "A cryptographic hash of a public X.509 certificate. This
  object should store the hash of the public X.509 certificate
  that the remote server should present during the TLS
  connection setup. The fingerprint of the presented
  certificate and this hash value MUST match exactly or the
  connection MUST NOT be established."
DEFVAL { "" }
::= { snmpTlstmAddr13Entry 1 }

snmpTlstmAddr13ServerIdentity OBJECT-TYPE
SYNTAX      SnmpAdminString
MAX-ACCESS  read-create
STATUS      current
DESCRIPTION
  "The reference identity to check against the identity
  presented by the remote system."
DEFVAL { "" }
::= { snmpTlstmAddr13Entry 2 }

snmpTlstmAddr13StorageType OBJECT-TYPE
SYNTAX       StorageType
MAX-ACCESS   read-create
STATUS       current
DESCRIPTION
  "The storage type for this conceptual row. Conceptual rows
  having the value 'permanent' need not allow write-access to
  any columnar objects in the row."
DEFVAL      { nonVolatile }
::= { snmpTlstmAddr13Entry 3 }

snmpTlstmAddr13RowStatus OBJECT-TYPE
SYNTAX      RowStatus
MAX-ACCESS  read-create
STATUS      current
DESCRIPTION
  "The status of this conceptual row. This object may be used
  to create or remove rows from this table.
  To create a row in this table, an administrator must set this
  object to either createAndGo(4) or createAndWait(5).
  Until instances of all corresponding columns are
  appropriately configured, the value of the
  corresponding instance of the snmpTlstmAddr13RowStatus
  column is notReady(3).
  In particular, a newly created row cannot be made active until
the corresponding snmpTlstmAddr13ServerFingerprint column has 
been set.
Rows MUST NOT be active if the snmpTlstmAddr13ServerFingerprint 
column is blank and the snmpTlstmAddr13ServerIdentity is set to 
'*' since this would insecurely accept any presented 
certificate.
The snmpTlstmAddr13ServerFingerprint object may not be modified 
while the value of this object is active(1).
An attempt to set these objects while the value of 
snmpTlstmAddr13RowStatus is active(1) will result in 
an inconsistentValue error.
::= { snmpTlstmAddr13Entry 4 }
.-- ************************************************
-- snmpTlstmNotifications - Notifications Information 
-- ************************************************

snmpTlstmServerCertificateUnknown NOTIFICATION-TYPE
OBJECTS { snmpTlstmSessionUnknownServerCertificate }
STATUS  current
DESCRIPTION
"Notification that the server certificate presented by an SNMP 
over (D)TLS server was invalid because no configured 
fingerprint or CA was acceptable to validate it. This may be 
because there was no entry in the snmpTlstmAddrTable (or 
snmpTlstmAddr13Table) or 
because no path could be found to known Certification 
Authority.
To avoid notification loops, this notification MUST NOT be 
sent to servers that themselves have triggered the 
notification."
::= { snmpTlstmNotifications 1 }

snmpTlstmServerInvalidCertificate NOTIFICATION-TYPE
OBJECTS { snmpTlstmAddrServerFingerprint, 
 snmpTlstmSessionInvalidServerCertificates }
STATUS  deprecated
DESCRIPTION
"Notification that the server certificate presented by an SNMP 
over (D)TLS server could not be validated even if the 
fingerprint or expected validation path was known. That is, a 
cryptographic validation error occurred during certificate 
validation processing.
To avoid notification loops, this notification MUST NOT be 
sent to servers that themselves have triggered the 
notification."
::= { snmpTlstmNotifications 2 }

snmpTlstmServerInvalidCertificate13 NOTIFICATION-TYPE
OBJECTS { snmpTlstmAddr13ServerFingerprint, 
 snmpTlstmSessionInvalidServerCertificates }
STATUS  current
DESCRIPTION
"Notification that the server certificate presented by an SNMP over TLS server could not be validated even if the fingerprint or expected validation path was known. That is, a cryptographic validation error occurred during certificate validation processing. To avoid notification loops, this notification MUST NOT be sent to servers that themselves have triggered the notification."

::= { snmpTlstmNotifications 3 }
-- ************************************************
-- snmpTlstmCompliances - Conformance Information
-- ************************************************

snmpTlstmCompliances OBJECT IDENTIFIER ::= { snmpTlstmConformance 1 }

snmpTlstmGroups OBJECT IDENTIFIER ::= { snmpTlstmConformance 2 }

-- Compliance statements
-- ************************************************

snmpTlstmCompliance MODULE-COMPLIANCE

STATUS       deprecated
DESCRIPTION  "The compliance statement for SNMP engines that support the SNMP-TLS-TM-MIB"

MODULE

MANDATORY-GROUPS { snmpTlstmStatsGroup,
                  snmpTlstmIncomingGroup,
                  snmpTlstmOutgoingGroup,
                  snmpTlstmNotificationGroup }

::= { snmpTlstmCompliances 1 }

snmpTlstmCompliance13 MODULE-COMPLIANCE

STATUS       current
DESCRIPTION  "The compliance statement for SNMP engines that support the SNMP-TLS-TM-MIB"

MODULE

MANDATORY-GROUPS { snmpTlstmStatsGroup,
                   snmpTlstmIncoming13Group,
                   snmpTlstmOutgoing13Group,
                   snmpTlstmNotification13Group }

::= { snmpTlstmCompliances 2 }

-- ************************************************
-- Units of conformance
-- ************************************************

snmpTlstmStatsGroup OBJECT-GROUP

OBJECTS {
    snmpTlstmSessionOpens,
    snmpTlstmSessionClientCloses,
    snmpTlstmSessionOpenErrors,
    ...}
snmpTlstmSessionAccepts,
snmpTlstmSessionServerCloses,
snmpTlstmSessionNoSessions,
snmpTlstmSessionInvalidClientCertificates,
snmpTlstmSessionUnknownServerCertificate,
snmpTlstmSessionInvalidServerCertificates,
snmpTlstmSessionInvalidCaches
}

STATUS       current
DESCRIPTION
"A collection of objects for maintaining
statistical information of an SNMP engine that
implements the SNMP TLS Transport Model."
::= { snmpTlstmGroups 1 }

snmpTlstmIncomingGroup OBJECT-GROUP
OBJECTS {
  snmpTlstmCertToTSNCount,
  snmpTlstmCertToTSNTableLastChanged,
  snmpTlstmCertToTSNFingerprint,
  snmpTlstmCertToTSNMapType,
  snmpTlstmCertToTSNData,
  snmpTlstmCertToTSNStorageType,
  snmpTlstmCertToTSNRowStatus
}

STATUS       deprecated
DESCRIPTION
"A collection of objects for maintaining
incoming connection certificate mappings to
tmSecurityNames of an SNMP engine that implements the
SNMP TLS Transport Model."
::= { snmpTlstmGroups 2 }

snmpTlstmOutgoingGroup OBJECT-GROUP
OBJECTS {
  snmpTlstmParamsCount,
  snmpTlstmParamsTableLastChanged,
  snmpTlstmParamsClientFingerprint,
  snmpTlstmParamsStorageType,
  snmpTlstmParamsRowStatus,
  snmpTlstmAddrCount,
  snmpTlstmAddrTableLastChanged,
  snmpTlstmAddrServerFingerprint,
  snmpTlstmAddrServerIdentity,
  snmpTlstmAddrStorageType,
  snmpTlstmAddrRowStatus
}

STATUS       deprecated
DESCRIPTION
"A collection of objects for maintaining
outgoing connection certificates to use when opening
connections as a result of SNMP-TARGET-MIB settings.

::= { snmpTlstmGroups 3 }

snmpTlstmNotificationGroup NOTIFICATION-GROUP

NOTIFICATIONS {
    snmpTlstmServerCertificateUnknown,
    snmpTlstmServerInvalidCertificate
}

STATUS deprecated

DESCRIPTION

"Notifications"

::= { snmpTlstmGroups 4 }

snmpTlstmIncoming13Group OBJECT-GROUP

OBJECTS {
    snmpTlstmCertToTSN13Count,
    snmpTlstmCertToTSN13TableLastChanged,
    snmpTlstmCertToTSN13Fingerprint,
    snmpTlstmCertToTSN13MapType,
    snmpTlstmCertToTSN13Data,
    snmpTlstmCertToTSN13StorageType,
    snmpTlstmCertToTSN13RowStatus
}

STATUS current

DESCRIPTION

"A collection of objects for maintaining
incoming connection certificate mappings to
tmSecurityNames of an SNMP engine that implements the
SNMP TLS 1.3 Transport Model."

::= { snmpTlstmGroups 5 }

snmpTlstmOutgoing13Group OBJECT-GROUP

OBJECTS {
    snmpTlstmParams13Count,
    snmpTlstmParams13TableLastChanged,
    snmpTlstmParams13ClientFingerprint,
    snmpTlstmParams13StorageType,
    snmpTlstmParams13RowStatus,
    snmpTlstmAddr13Count,
    snmpTlstmAddr13TableLastChanged,
    snmpTlstmAddr13ServerFingerprint,
    snmpTlstmAddr13ServerIdentity,
    snmpTlstmAddr13StorageType,
    snmpTlstmAddr13RowStatus
}

STATUS current

DESCRIPTION

"A collection of objects for maintaining
outgoing connection certificates to use when opening
TLS 1.3 connections as a result of SNMP-TARGET-MIB settings."
Internet-Draft  TLS 1.3 Transport Model for SNMP  June 2021

::= { snmpTlstmGroups 6 }

snmpTlstmNotification13Group NOTIFICATION-GROUP

NOTIFICATIONS {
    snmpTlstmServerCertificateUnknown,
    snmpTlstmServerInvalidCertificate13
}

STATUS current

DESCRIPTION

"Notifications for the SNMP TLS 1.3 Transport Model"

::= { snmpTlstmGroups 7 }

END

5. Security Considerations

This document updates a transport model that permits SNMP to utilize TLS security services. The security threats and how the TLS transport model mitigates these threats are covered throughout this document and in [RFC6353]. Security considerations for TLS are described in Section 10 and Appendix E of TLS 1.3 [RFC8446].

5.1. MIB Module Security

There are a number of management objects defined in this MIB module with a MAX-ACCESS clause of read-write and/or read-create. Such objects might be considered sensitive or vulnerable in some network environments. The support for SET operations in a non-secure environment without proper protection can have a negative effect on network operations. These are the tables and objects and their sensitivity/vulnerability:

* The snmpTlstmParams13Table can be used to change the outgoing X.509 certificate used to establish a TLS connection. Modifications to objects in this table need to be adequately authenticated since modifying the values in this table will have profound impacts to the security of outbound connections from the device. Since knowledge of authorization rules and certificate usage mechanisms might be considered sensitive, protection from disclosure of the SNMP traffic via encryption is automatically achieved via TLS 1.3.

* The snmpTlstmAddr13Table can be used to change the expectations of the certificates presented by a remote TLS server. Modifications to objects in this table need to be adequately authenticated since modifying the values in this table will have profound impacts to the security of outbound connections from the device. Since knowledge of authorization rules and certificate usage mechanisms might be considered sensitive, protection from disclosure of the SNMP traffic via encryption is automatically achieved via TLS 1.3.
* The snmpTlstmCertToTSN13Table is used to specify the mapping of incoming X.509 certificates to tmSecurityNames, which eventually get mapped to an SNMPv3 securityName. Modifications to objects in this table need to be adequately authenticated since modifying the values in this table will have profound impacts to the security of incoming connections to the device. Since knowledge of authorization rules and certificate usage mechanisms might be considered sensitive, protection from disclosure of the SNMP traffic via encryption is automatically achieved via TLS 1.3. When this table contains a significant number of rows it might affect the system performance when accepting new TLS connections.

Some of the readable objects in this MIB module (i.e., objects with a MAX-ACCESS other than not-accessible) might be considered sensitive or vulnerable in some network environments. It is thus important to control even GET and/or NOTIFY access to these objects and encrypt the values of these objects when sending them over the network via SNMP. These are the tables and objects and their sensitivity/vulnerability:

* This MIB contains a collection of counters that monitor the TLS connections being established with a device. Since knowledge of connection and certificate usage mechanisms might be considered sensitive, protection from disclosure of the SNMP traffic via encryption is automatically achieved via TLS 1.3.

SNMP versions prior to SNMPv3 did not include adequate security. Even if the network itself is secure (for example, by using IPsec), even then, there is no control as to who on the secure network is allowed to access and GET/SET (read/change/create/delete) the objects in this MIB module.

As defined in Section 2.4, TLSTM clients and servers MUST NOT request, offer, or use SNMPv1 or SNMPv2c message processing described in [RFC3584], or the User-based Security Model of SNMPv3. Instead, it is RECOMMENDED to deploy SNMPv3 and to enable cryptographic security. It is then a customer/operator responsibility to ensure that the SNMP entity giving access to an instance of this MIB module is properly configured to give access to the objects only to those principals (users) that have legitimate rights to indeed GET or SET (change/create/delete) them.

6. IANA Considerations

This document has no IANA actions beyond those performed as a part of [RFC6353].
7. Acknowledgements

Acknowledgements
This document is based on [RFC6353]. This document
was reviewed by the following people who helped provide useful
comments: Michaela Vanderveen.

8. References

8.1. Normative References

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Vaughn                  Expires 29 December 2021               [Page 39]
8.2. Informative References


Appendix A. Target and Notification Configuration Example

The following sections describe example configuration for the SNMP-TLS-TM-MIB, the SNMP-TARGET-MIB, the NOTIFICATION-MIB, and the SNMP-VIEW-BASED-ACM-MIB.

A.1. Configuring a Notification Originator

The following row adds the "Joe Cool" user to the "administrators" group:

```
vacmSecurityModel             = 4 (TSM)
vacmSecurityName              = "Joe Cool"
vacmGroupName                 = "administrators"
vacmSecurityToGroupStorageType = 3 (nonVolatile)
vacmSecurityToGroupStatus     = 4 (createAndGo)
```

The following row configures the snmpTlstmAddr13Table to use certificate path validation and to require the remote notification receiver to present a certificate for the "server.example.org" identity.

```
snmpTargetAddrName            = "toNRAddr"
snmpTlstmAddr13ServerFingerprint = ""
snmpTlstmAddr13ServerIdentity = "server.example.org"
snmpTlstmAddr13StorageType    = 3         (nonVolatile)
snmpTlstmAddr13RowStatus      = 4         (createAndGo)
```

The following row configures the snmpTargetAddrTable to send notifications using TLS/TCP to the snmptls-trap port at 192.0.2.1:

```
snmpTargetAddrName            = "toNRAddr"
snmpTargetAddrTDomain         = snmpTLSTCPDomain
snmpTargetAddrAddress         = "192.0.2.1:10162"
snmpTargetAddrTimeOut         = 1500
snmpTargetAddrRetryCount      = 3
snmpTargetAddrTagList         = "toNRTag"
snmpTargetAddrParams          = "toNR"         (MUST match below)
snmpTargetAddrStorageType     = 3         (nonVolatile)
snmpTargetAddrRowStatus       = 4         (createAndGo)
```
The following row configures the snmpTargetParamsTable to send the notifications to "Joe Cool", using authPriv SNMPv3 notifications through the TransportSecurityModel [[RFC5591]]:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>snmpTargetParamsName</td>
<td>&quot;toNR&quot; (MUST match above)</td>
</tr>
<tr>
<td>snmpTargetParamsSNMPModel</td>
<td>3 (SNMPv3)</td>
</tr>
<tr>
<td>snmpTargetParamsSecurityModel</td>
<td>4 (TransportSecurityModel)</td>
</tr>
<tr>
<td>snmpTargetParamsSecurityName</td>
<td>&quot;Joe Cool&quot;</td>
</tr>
<tr>
<td>snmpTargetParamsSecurityLevel</td>
<td>3 (authPriv)</td>
</tr>
<tr>
<td>snmpTargetParamsStorageType</td>
<td>3 (nonVolatile)</td>
</tr>
<tr>
<td>snmpTargetParamsRowStatus</td>
<td>4 (createAndGo)</td>
</tr>
</tbody>
</table>

A.2. Configuring TLSTM to Utilize a Simple Derivation of tmSecurityName

The following row configures the snmpTlstmCertToTSN13Table to map a validated client certificate, referenced by the client’s public X.509 hash fingerprint, to a tmSecurityName using the subjectAltName component of the certificate.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>snmpTlstmCertToTSN13ID</td>
<td>1 (chosen by ordering preference)</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13Fingerprint</td>
<td>HASH (appropriate fingerprint)</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13MapType</td>
<td>snmpTlstmCertSANAny</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13Data</td>
<td>&quot;&quot; (not used)</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13StorageType</td>
<td>3 (nonVolatile)</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13RowStatus</td>
<td>4 (createAndGo)</td>
</tr>
</tbody>
</table>

This type of configuration should only be used when the naming conventions of the (possibly multiple) Certification Authorities are well understood, so two different principals cannot inadvertently be identified by the same derived tmSecurityName.

A.3. Configuring TLSTM to Utilize Table-Driven Certificate Mapping

The following row configures the snmpTlstmCertToTSN13Table to map a validated client certificate, referenced by the client’s public X.509 hash fingerprint, to the directly specified tmSecurityName of "Joe Cool".

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>snmpTlstmCertToTSN13ID</td>
<td>2 (chosen by ordering preference)</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13Fingerprint</td>
<td>HASH (appropriate fingerprint)</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13MapType</td>
<td>snmpTlstmCertSpecified</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13SecurityName</td>
<td>&quot;Joe Cool&quot;</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13StorageType</td>
<td>3 (nonVolatile)</td>
</tr>
<tr>
<td>snmpTlstmCertToTSN13RowStatus</td>
<td>4 (createAndGo)</td>
</tr>
</tbody>
</table>
Author’s Address

Kenneth Vaughn (editor)
Trevilon LLC
6606 FM 1488 RD
Suite 148-503
Magnolia, TX 77354
United States of America

Phone: +1 571 331 5670
Email: kvaughn@trevilon.com
Abstract

This document defines a YANG data model for optical network inventory data information.

The YANG data model presented in this document is intended to be used as the basis toward a generic YANG data model for network inventory data information which can be augmented, when required, with technology-specific (e.g., optical) inventory data, to be defined either in a future version of this document or in another document.

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

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.
1. Introduction

Network inventory management is a key component in operators’ OSS architectures.
Network inventory is a fundamental functionality in network management and was specified many years ago. Given the emerging of data models and their deployment in operator's management and control systems, the traditional function of inventory management is also requested to be defined as a data model.

Network inventory management and monitoring is a critical part of ensuring the network stays healthy, well-planned, and functioning in the operator’s network. Network inventory management allows the operator to keep track of what physical network devices are staying in the network including relevant software and hardware.

The network inventory management also helps the operator to know when to acquire new assets and what is needed, or to decommission old or faulty ones, which can help to improve network performance and capacity planning.

In [I-D.ietf-teas-actn-poi-applicability] a gap was identified regarding the lack of a YANG data model that could be used at ACTN MPI interface level to report whole/partial hardware inventory information available at PNC level towards north-bound systems (e.g., MDSC or OSS layer).

[RFC8345] initial goal was to make possible the augmentation of the YANG data model with network inventory data model but this was never developed and the scope was kept limited to network topology data only.

It is key for operators to drive the industry towards the use of a standard YANG data model for network inventory data instead of using vendors proprietary APIs (e.g., REST API).

In the ACTN architecture, this would bring also clear benefits at MDSC level for packet over optical integration scenarios since this would enable the correlation of the inventory information with the links information reported in the network topology model.

The intention is to define a generic YANG data model that would be as much as possible technology agnostic (valid for IP, optical and microwave networks) and that could be augmented, when required, to include some technology-specific inventory details.

[RFC8348] defines a YANG data model for the management of the hardware on a single server and therefore it is more applicable to the PNC South Bound Interface (SBI) towards the network elements rather than at the PNC MPI. However, the YANG data model defined in [RFC8348] has been used as a reference for defining the YANG network inventory data model.
For optical network inventory, the network inventory YANG data model should support the use cases (4a and 4b) and requirements defined in [ONF_TR-547], in order to guarantee a seamless integration at MDSC/OSS/orchestration layers.

The proposed YANG data model has been analysed to cover the requirements and use cases for Optical Network Inventory.

Being based on [RFC8348], this data model should be a good starting point toward a generic data model and applicable to any technology. However, further analysis of requirements and use cases is needed to extend the applicability of this YANG data model to other types of networks (IP and microwave) and to identify which aspects are generic and which aspects are technology-specific for optical networks.

This document defines one YANG module: ietf-network-inventory.yang (Section 4).

Note: review in future versions of this document the related modules, depending on the augmentation relationship.

The YANG data model defined in this document conforms to the Network Management Datastore Architecture [RFC8342].

1.1. Terminology and Notations

Refer to [RFC7446] and [RFC7581] for the key terms used in this document. The following terms are defined in [RFC7950] and are not redefined here:

*  client
*  server
*  augment
*  data model
*  data node

The following terms are defined in [RFC6241] and are not redefined here:

*  configuration data

*  state data
The terminology for describing YANG data models is found in [RFC7950].

TBD: Recap the concept of chassis/slot/component/board/... in [TMF-MTOSI].

Following terms are used for the representation of the hierarchies in the optical network inventory.

Network Element:

a device installed on one or several shelves and can afford some specific transmission function independently.

Cabinet:

a holder of the device and provides power supply for the device in it.

Chassis:

a holder of the device installation.

Slot:

a holder of the board.

Component:

holders and equipments of the network element, including rack, shelf, slot, sub-slot, board and port.

Board/Card:

a pluggable equipment on the network element and can afford a specific transmission function independently.

Port:

an interface on board

1.2. Tree Diagram

A simplified graphical representation of the data model is used in Section 3 of this document. The meaning of the symbols in these diagrams is defined in [RFC8340].
1.3. 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.

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Yang Module</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ianahw</td>
<td>iana-hardware</td>
<td>[RFC8348]</td>
</tr>
<tr>
<td>ni</td>
<td>ietf-network-inventory</td>
<td>RFCXXX</td>
</tr>
<tr>
<td>yang</td>
<td>ietf-yang-types</td>
<td>[RFC6991]</td>
</tr>
</tbody>
</table>

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. YANG Data Model for Optical Network Inventory

2.1. YANG Model Overview

Based on TMF classification in [TMF-MTOSI], inventory objects can be divided into two groups, holder group and equipment group. The holder group contains rack, shelf, slot, sub-slot while the equipment group contains network-element, board and port. With the requirement of GIS and on-demand domain controller selection raised, the equipment room becomes a new inventory object to be managed besides TMF classification.

Logically, the relationship between these inventory objects can be described by Figure 1 below:
In [RFC8348], rack, shelf, slot, sub-slot, board and port are defined as components of network elements with generic attributes.

While [RFC8348] is used to manage the hardware of a single server (e.g., a Network Element), the Network Inventory YANG data model is used to retrieve the network inventory information that a controller discovers from multiple Network Elements under its control.
However, the YANG data model defined in [RFC8348] has been used as a reference for defining the YANG network inventory data model. This approach can simplify the implementation of this network inventory model when the controller uses the YANG data model defined in [RFC8348] to retrieve the hardware configuration from the network elements under its control.

Note: review in future versions of this document which attributes from [RFC8348] are required also for network inventory and whether there are attributes not defined in [RFC8348] which are required for network inventory.

Note: review in future versions of this document whether to re-use definitions from [RFC8348] or use schema-mount.

```yaml
+--ro network-inventory
  +--ro equipment-rooms
    +--ro equipment-room* [uuid]
      +--ro uuid         yang:uuid
      ...................................
    +--ro rack* [uuid]
      +--ro uuid        yang:uuid
      ...................................
    +--ro shelves* [uuid]
      +--ro uuid         yang:uuid
      ...................................
      +--ro chassis-ref
      +--ro ne-ref?       leafref
      +--ro component-ref? leafref
  +--ro network-elements
    +--ro network-element* [uuid]
      +--ro uuid         yang:uuid
      ...................................
    +--ro components
      +--ro component* [uuid]
      +--ro uuid         yang:uuid
      ...................................
```

The YANG data model for network inventory follows the same approach of [RFC8348] and reports the network inventory as a list of components of different types (e.g., chassis, module, port).
++--ro components
  +--ro component* [uuid]
    +--ro uuid                yang:uuid
    +--ro name?               string
    +--ro description?        string
    +--ro class?              identityref
    +--ro parent-rel-pos?     int32
    +--ro children* [child-ref]
      |  +--ro child-ref        -> ../../../uuid
    +--ro parent
      +--ro parent-ref?       -> ../../../uuid

Note: review in future versions of this document whether the component list should be under the network-inventory instead of under the network-element container.

However, considering there are some special scenarios, the relationship between the rack and network elements is not 1 to 1 nor 1 to n. The network element cannot be the direct parent node of the rack. So there should be n to m relationship between racks and network elements. And the shelves in the rack should have some reference information to the component.

Note that in [RFC8345], topology and inventory are two subsets of network information. However, considering the complexity of the existing topology models and to have a better extension capability, we define a separate root for the inventory model. We will consider some other ways to do some associations between the topology model and inventory model in the future.

Note: review in future versions of this document whether network inventory should be defined as an augmentation of the network model defined in [RFC8345] instead of under a new network-inventory root.

The proposed YANG data model has been analysed to cover the requirements and use cases for Optical Network Inventory.

Further analysis of requirements and use cases is needed to extend the applicability of this YANG data model to other types of networks (IP and microwave) and to identify which aspects are generic and which aspects are technology-specific for optical networks.

3. Optical Network Inventory Tree Diagram

Figure 2 below shows the tree diagram of the YANG data model defined in module ietf-network-inventory.yang (Section 4).
4. YANG Model for Optical Network Inventory

<CODE BEGINS> file "ietf-network-inventory@2021-11-10.yang"
module ietf-network-inventory {
    yang-version 1.1;
    namespace "urn:ietf:params:xml:ns:yang:ietf-network-inventory";
    prefix ni;

    import ietf-yang-types {
        prefix yang;
        reference

Figure 2: Network inventory tree diagram
This version of this YANG module is part of RFC XXXX; see
the RFC itself for full legal notices.

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 (RFC 2119) (RFC 8174) when, and only when,
they appear in all capitals, as shown here.

// RFC Ed.: replace XXXX with actual RFC number and remove this
// note.
// RFC Ed.: update the date below with the date of RFC publication
// and remove this note.

revision 2021-11-10 {
    description
        "Initial revision.";
    reference
        "draft-yg3bp-ccamp-optical-inventory-yang-01: A YANG Data
         Model for Optical Network Inventory.";
}

container network-inventory {
    config false;
    description
        "The top-level container for the network inventory
         information.";
    uses equipment-rooms-grouping;
    uses network-elements-grouping;
}

grouping common-entity-attributes {
    description
        "A set of attributes which are common to all the entities
         (e.g., component, equipment room) defined in this module.";
    leaf uuid {
        type yang:uuid;
        description
            "Uniquely identifies an entity (e.g., component).";
    }
    leaf name {
        type string;
        description
            "A name for an entity (e.g., component), as specified by
             a network manager, that provides a non-volatile 'handle'
             for the entity and that can be modified anytime during the
             entity lifetime.";
    }
}
If no configured value exists, the server MAY set the value of this node to a locally unique value in the operational state. \\
}
]
grouping network-elements-grouping {
  description "The attributes of the network elements.";
  container network-elements {
    description "The container for the list of network elements.";
    list network-element {
      key uuid;
      description "The list of network elements within the network.";
      uses common-entity-attributes;
      uses components-grouping;
    }
  }
}
}
]
grouping equipment-rooms-grouping {
  description "The attributes of the equipment rooms.";
  container equipment-rooms {
    description "The container for the list of equipment rooms.";
    list equipment-room {
      key uuid;
      description "The list of equipment rooms within the network.";
      uses common-entity-attributes;
      leaf location {
        type string;
        description "compared with the location information of the other inventory objects, a GIS address is preferred for equipment room";
      }
      list rack {
        key uuid;
        description "The list of racks within an equipment room.";
        uses common-entity-attributes;
        leaf row-number {
          type uint32;
          description "Identifies the row within the equipment room where
the rack is located."
}

leaf rack-number {
  type uint32;
  description
    "Identifies the physical location of the rack within
    the row.";
}

list shelves {
  key uuid;
  description
    "The list of shelves within a rack.";
  uses common-entity-attributes;

  leaf shelf-number {
    type uint8;
    description
      "Identifies the location of the shelf within the
      rack.";
  }

  container chassis-ref {
    description
      "The reference to the network element component
      representing this shelf.";

    leaf ne-ref {
      type leafref {
      }
      description
        "The reference to the network element containing
        the component.";
    }

    leaf component-ref {
      type leafref {
      }
      description
        "The reference to the component within the network
        element.";
    }
  }
}
grouping components-grouping {
  description
  "The attributes of the hardware components.";
  container components {
    description
    "The container for the list of components.";
    list component {
      key uuid;
      description
      "The list of components within a network element.";
      uses common-entity-attributes;
      leaf description {
        type string;
        description
        "A textual description of the component.";
        reference
        "RFC 8348: A YANG Data Model for Hardware Management.";
      }
      leaf class {
        type identityref {
          base ianahw:hardware-class;
        }
        description
        "An indication of the general hardware type of the
        component.";
        reference
        "RFC 8348: A YANG Data Model for Hardware Management.";
      }
      leaf parent-rel-pos {
        type int32 {
          range "0 .. 2147483647";
        }
        description
        "An indication of the relative position of this child
        component among all its sibling components. Sibling
        components are defined as components that:

        o share the same value of the 'parent' node and

        o share a common base identity for the 'class' node.";
        reference
        "RFC 8348: A YANG Data Model for Hardware Management.";
      }
    list children {
      key child-ref;
      description
"The child components that are physically contained by this component."

leaf child-ref {
  type leafref {
    path "../../ni:uuid";
  }
  description
    "The reference to the child component."
}

container parent {
  description
    "The parent component that physically contains this component.

    If this container is not instantiated, it indicates that this component is not contained in any other component.

    In the event that a physical component is contained by more than one physical component (e.g., double-wide modules), this container contains the data of one of these components. An implementation MUST use the same component every time this container is instantiated."
  leaf parent-ref {
    type leafref {
      path "../../ni:uuid";
    }
    description
      "The reference to the parent component."
  }
}

Figure 3: Network inventory YANG module

5. Manageability Considerations

<Add any manageability considerations>
6. Security Considerations

<Add any security considerations>

7. IANA Considerations

<Add any IANA considerations>

8. References

8.1. Normative References


8.2. Informative References

[I-D.ietf-teas-actn-poi-applicability]

[ONF_TR-547]

[RFC8345]

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Authors’ Addresses

Chaode Yu
Huawei Technologies

Email: yuchaode@huawei.com