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Applying COSE Signatures for YANG Data Provenance
draft-ietf-opsawg-yang-provenance-02

Abstract

This document defines a mechanism based on COSE signatures to provide and verify the provenance of YANG data, so it is possible to verify the origin and integrity of a dataset, even when those data are going to be processed and/or applied in workflows where a crypto-enabled data transport directly from the original data stream is not available. As the application of evidence-based OAM automation and the use of tools such as AI/ML grow, provenance validation becomes more relevant in all scenarios, in support of the assuring the origin and integrity of datasets and/or data streams. The use of compact signatures facilitates the inclusion of provenance strings in any YANG schema requiring them.

About This Document

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

The latest revision of this draft can be found at <https://dr2lopez.github.io/yang-provenance/draft-ietf-opsawg-yang-provenance.html>. Status information for this document may be found at <https://datatracker.ietf.org/doc/draft-ietf-opsawg-yang-provenance/>.

Discussion of this document takes place on the Operations and Management Area Working Group Working Group mailing list (<mailto:opsawg@ietf.org>), which is archived at <https://mailarchive.ietf.org/arch/browse/opsawg/>. Subscribe at <https://www.ietf.org/mailman/listinfo/opsawg/>.

Source for this draft and an issue tracker can be found at <https://github.com/dr2lopez/yang-provenance>.

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. Introduction

OAM automation, generally based on closed-loop principles, requires at least two datasets to be used. Using the common terms in Control Theory, we need those from the plant (the network device or segment under control) and those to be used as reference (the desired values of the relevant data). The usual automation behavior compares these values and takes a decision, by whatever the method (algorithmic, rule-based, an AI model tuned by ML...) to decide on a control action according to this comparison. Assurance of the origin and integrity of these datasets, what we refer in this document as "provenance", becomes essential to guarantee a proper behavior of closed-loop automation.

When datasets are made available as an online data flow, provenance can be assessed by properties of the data transport protocol, as long as some kind of cryptographic protocol is used for source authentication, with TLS, SSH and IPsec as the main examples. But when these datasets are stored, go through some pre-processing or aggregation stages, or even cryptographic data transport is not available, provenance must be assessed by other means.

The original use case for this provenance mechanism is associated with [YANGmanifest], in order to provide a proof of the origin and integrity of the provided metadata, and therefore the examples in this document use the modules described there, but it soon became clear that it could be extended to any YANG datamodel to support provenance evidence. An analysis of other potential use cases suggested the interest of defining an independent, generally applicable mechanism.

Provenance verification by signatures incorporated in YANG data can be applied to any data processing pipeline, whether they rely on an online flow or use some kind of data store, such as data lakes or time-series databases. The application of recorded data for ML training or validation constitute the most relevant examples of these scenarios.

This document provides a mechanism for including digital signatures within YANG data. It applies COSE [RFC9052] to make the signature compact and reduce the resources required for calculating it. This mechanism is applicable to any serialization of the YANG data supporting a clear method for canonicalization, but this document considers three base ones: CBOR, JSON and XML.

1.1. Target Deployment Scenarios

The provenance mechanisms described in this document are designed to be flexible and applicable in multiple deployment contexts within operational and management practices. The following non-exhaustive list provides examples of intended deployment scenarios:

- * **Device Configuration Integrity:** Digital signatures may be applied to device configuration elements to ensure that specific configuration fragments originate from an authorized source (e.g., controller, automation system) and have not been altered in transit. This is useful for zero-touch provisioning and secure configuration distribution in programmable networks.
- * **Telemetry and Monitoring Data:** When applied to operational state or streaming telemetry data (e.g., YANG-Push updates or Subscription Notifications), provenance signatures can help verify the integrity and authenticity of data collected from network elements, especially when the data may traverse untrusted collection pipelines.

- * Network-Wide Service Orchestration: In multi-vendor or multi-domain environments, provenance can be used to track and validate contributions from different orchestrators or domain controllers in composite service models. This enables trustable service chaining and auditability.

2. Conventions and Definitions

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 term "data provenance" refers to a documented trail accounting for the origin of a piece of data and where it has moved from to where it is presently. The signature mechanism provided here can be recursively applied to allow this accounting for YANG data.

3. Defining Provenance Elements

The provenance for a given YANG element MUST be conveyed by a leaf element, containing the COSE signature bitstring built according to the procedure defined below in this section. The provenance leaf MUST be of type provenance-signature, defined as follows:

```
typedef provenance-signature {  
    type binary;  
    description  
        "The provenance-signature type represents a digital signature  
        corresponding to the associated YANG element. The signature is based  
        on COSE and generated using a canonicalized version of the  
        associated element.";  
    reference  
        "RFC 9052: CBOR Object Signing and Encryption (COSE): Structures and Process  
        draft-ietf-opsawg-yang-provenance";  
}
```

The use of this type is the proper method for identifying signature leaves, and therefore whenever this type is used for a leaf element, it MUST be considered a provenance signature element, to be generated or verified according to the procedures described in this section.

3.1. Provenance Signature Strings

Provenance signature strings are COSE single signature messages with [nil] payload, according to COSE conventions and registries, and with the following structure (as defined by [RFC9052], Section 4.2):

```
COSE_Sign1 = [  
  protected /algorithm-identifier, kid, serialization-method/  
  unprotected /algorithm-parameters/  
  signature /using as external data the content of the YANG  
             (meta-)data without the signature leaf/  
]
```

The COSE_Sign1 procedure yields a bitstring when building the signature and expects a bitstring for checking it, hence the proposed type for provenance signature leaves. The structure of the COSE_Sign1 consists of:

- * The algorithm-identifier, which MUST follow COSE conventions and registries.
- * The kid (Key ID), to be locally agreed, used and interpreted by the signer and the signature validator. URIs [RFC3986] and RFC822-style [RFC5322] identifiers are typical values to be used as kid.
- * The serialization-method, a string identifying the YANG serialization in use. It MUST be one of the three possible values "xml" (for XML serialization [RFC7950]), "json" (for JSON serialization [RFC7951]) or "cbor" (for CBOR serialization [RFC9254]).
- * The value algorithm-parameters, which MUST follow the COSE conventions for providing relevant parameters to the signing algorithm.
- * The signature for the YANG element provenance is being established for, to be produced and verified according to the procedure described below for each one of the enclosing methods for the provenance string described below.

3.2. Signature and Verification Procedures

To keep a concise signature and avoid the need for wrapping YANG constructs in COSE envelopes, the whole signature MUST be built and verified by means of externally supplied data, as defined in [RFC9052], Section 4.3, with a [nil] payload.

The byte strings to be used as input to the signature and verification procedures MUST be built by:

- * Selecting the exact YANG content to be used, according to the corresponding enclosing methods.

- * Applying the corresponding canonicalization method as described in the following section.

In order to guarantee proper verification, the signature procedure **MUST** be the last action to be taken before the YANG construct being signed is made available, whatever the means (sent as a reply to a poll or a notification, written to a file or record, etc.), and verification **SHOULD** take place in advance of any processing by the consuming application. The actions to be taken if the verification fails are specific to the consuming application, but it is **RECOMMENDED** to at least issue an error warning.

3.3. Canonicalization

Signature generation and verification require a canonicalization method to be applied, that depends on the serialization used. According to the three types of serialization defined, the following canonicalization methods **MUST** be applied:

- * For CBOR, length-first core deterministic encoding, as defined by [RFC8949].
- * For JSON, JSON Canonicalization Scheme (JCS), as defined by [RFC8785].
- * For XML, Exclusive XML Canonicalization 1.0, as defined by [XMLSig].

3.4. Provenance-Signature YANG Module

This module defines a provenance-signature type to be used in other YANG modules.

```
<CODE BEGINS> file "ietf-yang-provenance@2025-05-09.yang"
module ietf-yang-provenance {
  yang-version 1.1;
  namespace
    "urn:ietf:params:xml:ns:yang:ietf-yang-provenance";
  prefix iyangprov;

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

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```

description

"Defines a binary provenance-signature type to be used in other YANG modules.

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

revision 2025-05-09 {

description

"First revision";

reference

"RFC XXXX: Applying COSE Signatures for YANG Data Provenance";

}

typedef provenance-signature {

type binary;

description

"The provenance-signature type represents a digital signature corresponding to the associated YANG element. The signature is based on COSE and generated using a canonicalized version of the associated element.";

reference

"RFC XXXX: Applying COSE Signatures for YANG Data Provenance";

}

}

<CODE ENDS>

4. Enclosing Methods

Once defined the procedures for generating and verifying the provenance signature string, let's consider how these signatures can be integrated with the associated YANG data by enclosing the signature in the data structure. This document considers four different enclosing methods, suitable for different stages of the YANG schema and usage patterns of the YANG data. The enclosing method defines not only how the provenance signature string is combined with the signed YANG data but also the specific procedure for selecting the specific YANG content to be processed when signing and verifying.

Appendix A includes a set of examples of the different enclosing methods, applied to the same YANG fragment, to illustrate their use.

4.1. Including a Provenance Leaf in a YANG Element

This enclosing method requires a specific element in the YANG schema defining the element to be signed (the enclosing element), and thus implies considering provenance signatures when defining a YANG module, or the use of augmentation to include the provenance signature element in a existing YANG module.

When defining a provenance signature leaf element to appear in a YANG schema by means of this enclosing method, the provenance-signature leaf MAY be defined to be at any position in the enclosing element, but only one such leaf MUST be defined for this enclosing element. If the enclosing element contains other non-leaf elements, they MAY define their own provenance-signature leaf, according to the same rule. In this case, the provenance-signature leaves in the children elements are applicable to the specific child element where they are enclosed, while the provenance-signature leaf enclosed in the top-most element is applicable to the whole element contents, including the children provenance-signature leaf themselves. This allows for recursive provenance validation, data aggregation, and the application of provenance verification of relevant children elements at different stages of any data processing pipeline.

The specific YANG content to be processed SHALL be generated by taking the whole enclosing element and eliminating the leaf containing the provenance signature string.

As example, let us consider the two modules proposed in [YANGmanifest]. For the platform-manifest module, the provenance for a platform would be provided by augmenting the current schema with the optional platform-provenance leaf shown below:

```

module: ietf-platform-manifest
  +--ro platforms
    +--ro platform* [id]
      +--ro id string
      +--ro name? string
      +--ro vendor? string
      +--ro vendor-pen? uint32
      +--ro software-version? string
      +--ro software-flavor? string
      +--ro os-version? string
      +--ro os-type? string
      +--ro platform-provenance? provenance-signature
      +--ro yang-push-streams
        | +--ro stream* [name]
        |   +--ro name
        |   +--ro description?
      +--ro yang-library
      + . . .
      .
      .
      .

```

For data collections, the provenance of each one would be provided by augmenting the schema with an optional collector-provenance leaf, as shown below:

```

module: ietf-data-collection-manifest
  +--ro data-collections
    +--ro data-collection* [platform-id]
    +--ro platform-id
      | -> /p-mf:platforms/platform/id
    +--ro collector-provenance? provenance-signature
    +--ro yang-push-subscriptions
      +--ro subscription* [id]
        +--ro id
          | sn:subscription-id
        +
        .
        .
        .
      + . . .
      |
      .
      .
      .

```

Note how, in the two examples, the element bearing the provenance signature appears at different positions in the enclosing element. And note that, for processing the element for signature generation and verification, the signature element **MUST** be eliminated from the enclosing element before applying the corresponding canonicalization method.

Note that, in application of the recursion mechanism described above, a provenance element could be included at the top of any of the collections, supporting the verification of the provenance of the collection itself (as provided by a specific collector), without interfering with the verification of the provenance of each of the collection elements. As an example, in the case of the platform manifests it would look like:

```
module: ietf-platform-manifest
  +--ro platforms
    +--ro platform-collection-provenance? provenance-signature
    +--ro platform* [id]
      +--ro platform-provenance?          provenance-signature
      +--ro id                            string
      +--ro name?                          string
      +--ro vendor?                        string
      + . . .
      .
      .
      .
```

Note here that, to generate the YANG content to be processed in the case of the collection the provenance leafs of the individual elements **SHALL NOT** be eliminated, as it **SHALL** be the case when generating the YANG content to be processed for each individual element in the collection.

4.2. Including a Provenance Signature in YANG-Push Notifications

The signature mechanism proposed in this document **MAY** be used with YANG-Push [RFC8641] to sign notifications generated directly by publisher nodes. The signature is carried inside the notification envelope header defined in [I-D.ietf-netconf-notif-envelope] as a new extension.

The YANG content to be processed **MUST** consist of the content defined by the "contents" element in [I-D.ietf-netconf-notif-envelope].

The following sections define the YANG module that augments the "ietf-yp-notification" module. It extends the notification envelope header with a new leaf for the provenance signature and an augmentation to the "ietf-notification-capabilities" to enable clients discover the support of the provenance signature.

4.2.1. YANG Tree Diagram

The following is the YANG tree diagram [RFC8340] for the "ietf-yp-provenance" module.

```
module: ietf-yp-provenance

  augment /sysc:system-capabilities/notc:subscription-capabilities
    /inotenv:notification-metadata/inotenv:metadata:
      +--ro notification-provenance?   boolean

  augment-structure /inotenv:envelope:
    +-- provenance?   iyangprov:provenance-signature
```

And the following is the full YANG tree diagram for the notification structure.

```
module: ietf-notification

  structure envelope:
    +-- event-time          yang:date-and-time
    +-- hostname?          inet:host
    +-- sequence-number?   yang:counter32
    +-- provenance?        iyangprov:provenance-signature
    +-- contents?          <anydata>
```

Unlike the first enclosing method, in this second enclosing method the provenance leaf is added by augmenting a structure (/inotenv:envelope). The provenance leaf is inserted before the contents leaf. This ordering is important because the provenance signature MUST cover the content of the notification but MUST NOT include itself in the signature computation. This ensures the signature remains valid and verifiable. YANG augmented structures typically respect the convention that the anydata node, when present, should appear as the last element in the structure. Therefore, any newly augmented elements are automatically placed before it.

4.2.2. YANG Module

The "ietf-yp-provenance" module augments "ietf-yp-notification" module [I-D.ietf-netconf-notif-envelope] adding the provenance leaf to the notification envelope structure. It also adds the notification-provenance capability to allow clients to discover if provenance signatures are supported.

```
<CODE BEGINS> file "ietf-yp-provenance@2024-05-09.yang"
module ietf-yp-provenance {
  yang-version 1.1;
  namespace
    "urn:ietf:params:xml:ns:yang:ietf-yp-provenance";
  prefix inotifprov;

  import ietf-system-capabilities {
    prefix sysc;
    reference
      "RFC 9196: YANG Modules Describing Capabilities for
      Systems and Datastore Update Notifications";
  }
  import ietf-notification-capabilities {
    prefix notc;
    reference
      "RFC 9196: YANG Modules Describing Capabilities for
      Systems and Datastore Update Notifications";
  }
  import ietf-yang-provenance {
    prefix iyangprov;
    reference
      "RFC XXXX: Applying COSE Signatures for YANG Data Provenance";
  }
  import ietf-yang-structure-ext {
    prefix sx;
    reference
      "RFC 8791: YANG Data Structure Extensions";
  }
  import ietf-yp-notification {
    prefix inotenv;
    reference
      "RFC YYYY: Extensible YANG Model for YANG-Push Notifications";
  }

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

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description

"Defines a binary provenance-signature type to be used in other YANG modules.

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

```
revision 2025-05-09 {
  description
    "First revision";
  reference
    "RFC XXXX: Applying COSE Signatures for YANG Data Provenance";
}

sx:augment-structure "/inotenv:envelope" {
  leaf provenance {
    type iyangprov:provenance-signature;
    description
      "COSE signature of the content of the Notification for
      provenance verification.";
  }
}

augment "/sysc:system-capabilities"
  + "/notc:subscription-capabilities"
  + "/inotenv:notification-metadata/inotenv:metadata" {
  description
    "Extensions to Notification Capabilities enabling clients to
    know whether the provenance signature is supported.";
  leaf notification-provenance {
    type boolean;
    default "false";
  }
}
```

```

        description
          "Support of the provenance signature on YANG-Push
          Notifications.";
      }
    }
  }
<CODE ENDS>

```

4.3. Including Provenance as Metadata in YANG Instance Data

Provenance signature strings can be included as part of the metadata in YANG instance data files, as defined in [RFC9195] for data at rest. The augmented YANG tree diagram including the provenance signature is as follows:

```

module: ietf-yang-instance-data-provenance
  augment-structure /id:instance-data-set:
    +-- provenance?    iyangprov:provenance-signature

    *Note:* As in the second enclosing method, since this is a data
    structure, the provenance leaf appears before the content-data
    element.

```

The resulting YANG tree structure is:

```

structure instance-data-set:
+ . . .
+-- timestamp?          yang:date-and-time
+-- provenance?         iyangprov:provenance-signature
+-- content-data?       <anydata>

```

The provenance signature defined in this enclosing method applies to the whole content of the instance-data-set structure. This is independent of any other provenance signature strings that might be present within the content-data itself through other enclosing methods.

The specific YANG content to be processed SHALL be generated by taking the contents of instance-data-set structure, excluding the provenance signature element itself and applying the corresponding canonicalization method.

4.3.1. YANG Module

This module defines the provenance signature element to be included as metadata of a YANG data instance.

```
<CODE BEGINS>
file "ietf-yang-instance-data-provenance@2025-07-07.yang"
module ietf-yang-instance-data-provenance {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-yang-instance-data-provenance";
  prefix "yidprov";
  import ietf-yang-instance-data {
    prefix "id";
    reference
      "RFC 9195 A File Format for YANG Instance Data"
  }
  import ietf-yang-provenance {
    prefix iyangprov;
    reference
      "RFC XXXX: Applying COSE Signatures for YANG Data Provenance";
  }
  import ietf-yang-structure-ext {
    prefix sx;
    reference
      "RFC 8791: YANG Data Structure Extensions";
  }
  organization "IETF OPSAWG (Operations and Management Area Working Group)";
  contact
    "WG Web:    <https://datatracker.ietf.org/wg/opsawg/>
    WG List:    <mailto:opsawg@ietf.org>

    Authors:    Ana Mendez
                 <mailto:ana.mendezperz@telefonica.com>
                 Diego Lopez
                 <mailto:diego.r.lopez@telefonica.com>";
  description
    "Defines a binary provenance-signature type to be used as metadata
    in a YANG data instance.

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    This version of this YANG module is part of RFC XXXX; see the RFC
    itself for full legal notices.";
  revision 2025-07-07 {
    description "First revision.";
```



```

    reference "RFC XXXX: Applying COSE Signatures for YANG Data Provenance";
  }
  sx:augment-structure "/id:instance-data-set" {
    leaf provenance {
      type iyangprov:provenance-signature;
      description
        "Provenance signature that applies to the full content-data block of an instance dataset. This signature can be used to verify the integrity and authenticity of the instance data.";
    }
  }
}
<CODE ENDS>

```

4.4. Including Provenance in YANG Annotations

The use of annotations as defined in [RFC7952] seems a natural enclosing method, dealing with the provenance signature string as metadata extension and not requiring modification of existing YANG schemas. The provenance-string annotation is defined as follows:

```

md:annotation provenance {
  type provenance-signature;
  description
    "This annotation contains a digital signature corresponding to the YANG element in which it appears.";
}

```

The specific YANG content to be processed SHALL be generated by eliminating the provenance annotation (encoded according to what is described in Section 5 of [RFC7952]) from the element it applies to, before invoking the corresponding canonicalization method. In application of the general recursion principle for provenance signature strings, any other provenance strings within the element to which the provenance-string applies SHALL be left as they appear, whatever the enclosing method used for them.

4.4.1. YANG Module

This module defines a metadata annotation to include a provenance signature for a YANG element.

```

<CODE BEGINS> file "ietf-yang-provenance-annotation@2024-06-30.yang"
module ietf-yang-provenance-annotation {
  yang-version 1.1;
  namespace
    "urn:ietf:params:xml:ns:yang:ietf-yang-annotation-pmd";
  prefix "ypmd";
  import ietf-yang-metadata {
    prefix "md";
  }
}

```

```
}
organization "IETF OPSAWG (Operations and Management Area Working Group)";
contact
  "WG Web:    <https://datatracker.ietf.org/wg/opsawg/>
  WG List:    <mailto:opsawg@ietf.org>

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            Henk Birkholz
            <mailto:henk.birkholz@sit.fraunhofer.de>";
description
  "Defines a binary provenance-signature type to be used in YANG
  metadata annotations

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  authors of the code. All rights reserved.

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

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

revision 2024-06-30 {
  description
    "First revision";
  reference
    "RFC XXXX: Applying COSE Signatures for YANG Data Provenance";
}
md:annotation provenance {
  type yang:provenance-signature;
  description
    "This annotation contains the provenance signature for
    the YANG element associated with it";
}
}
<CODE ENDS>
```

5. Security Considerations

The provenance assessment mechanism described in this document relies on COSE [RFC9052] and the deterministic encoding or canonicalization procedures described by [RFC8949], [RFC8785] and [XMLSig]. The security considerations made in these references are fully applicable here.

The verification step depends on the association of the kid (Key ID) with the proper public key. This is a local matter for the verifier and its specification is out of the scope of this document. Similarly, key association with reliable data sources is a deployment decision, though a couple of deployment patterns can be considered, depending on the application scenario under consideration. On the one hand, identities may be associated to controller entities (a domain controller, a person in charge of operational aspects, an organizational unit managing an administrative domain, ec.) owning the private keys to be use in generating the provenance signatures for YANG data such as configurations or telemetry. Alternatively, individual devices may hold the identities and corresponding private keys to generate provenance signatures for locally originated data (e.g., telemetry updates). The use of certificates, PKI mechanisms, or any other secure out-of-band distribution of id-public key mappings is RECOMMENDED.

6. IANA Considerations

6.1. IETF XML Registry

This document registers the following URIs in the "IETF XML Registry" [RFC3688]:

URI: urn:ietf:params:xml:ns:yang:ietf-yang-provenance

Registrant Contact: The IESG.

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

URI: urn:ietf:params:xml:ns:yang:ietf-yp-provenance

Registrant Contact: The IESG.

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

URI: urn:ietf:params:xml:ns:yang:ietf-yang-instance-data-provenance

Registrant Contact: The IESG.

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

URI: urn:ietf:params:xml:ns:yang:ietf-yang-annotation-pmd

Registrant Contact: The IESG.

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

6.2. YANG Module Name

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

```
name: ietf-yang-provenance
namespace: urn:ietf:params:xml:ns:yang:ietf-yang-provenance
prefix: iyangprov
reference: RFC XXXX
```

```
name: ietf-yp-provenance
namespace: urn:ietf:params:xml:ns:yang:ietf-yp-provenance
prefix: inotifprov
reference: RFC XXXX
```

```
name: ietf-yang-instance-data-provenance
namespace: urn:ietf:params:xml:ns:yang:ietf-yang-instance-data-provenance
prefix: yidprov
reference: RFC XXXX
```

```
name: ietf-yang-provenance-annotation
namespace: urn:ietf:params:xml:ns:yang:ietf-yang-annotation-pmd
prefix: ypmmd
reference: RFC XXXX
```

7. Implementation Status

An open-source reference implementation, written in Java, is available at <https://github.com/tefiros/cose-provenance> (<https://github.com/tefiros/cose-provenance>). This implementation has been used to generate the examples in the appendix of this document, and was first demonstrated at the IETF 122 Hackathon. Work is ongoing to explore its integration with other open-source YANG modules. A Kafka message broker integration was presented at the IETF 123 Hackathon aiming at convergence with current efforts on YANG Push. The implementation is available at <https://github.com/tefiros/kafka-provenance> (<https://github.com/tefiros/kafka-provenance>).

8. References

8.1. Normative References

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8.2. Informative References

- [RFC7223] Bjorklund, M., "A YANG Data Model for Interface Management", RFC 7223, DOI 10.17487/RFC7223, May 2014, <<https://www.rfc-editor.org/rfc/rfc7223>>.

[YANGmanifest]

Claise, B., Quilbeuf, J., Lopez, D., Martinez-Casanueva, I. D., and T. Graf, "A Data Manifest for Contextualized Telemetry Data", Work in Progress, Internet-Draft, draft-ietf-opsawg-collected-data-manifest-09, 21 July 2025, <<https://datatracker.ietf.org/doc/html/draft-ietf-opsawg-collected-data-manifest-09>>.

Appendix A. Examples of Application of the Different Enclosing Methods

In the examples that follow, the signature strings have been wrapped and, in some cases, indented to improve readability. If these examples are used for any kind of validation, all intermediate carriage returns and whitespace should be deleted to build the actual signature string to be considered.

XML

Let us consider the following YANG instance, corresponding to a monitoring interface statement, as defined in [RFC7223]:

```
<?xml version="1.0" encoding="UTF-8"?>
<interfaces xmlns="urn:ietf:params:xml:ns:yang:ietf-interfaces">
  <interface>
    <name>GigabitEthernet1</name>
    <type xmlns:ianaift="urn:ietf:params:xml:ns:yang:iana-if-type">
      ianaift:ethernetCsmacd</type>
    <admin-status>up</admin-status>
    <oper-status>up</oper-status>
    <last-change>2024-02-03T11:22:41.081+00:00</last-change>
    <if-index>1</if-index>
    <phys-address>0c:00:00:37:d6:00</phys-address>
    <speed>1000000000</speed>
    <statistics>
      <discontinuity-time>2024-02-03T11:20:38+00:00</discontinuity-time>
      <in-octets>8157</in-octets>
      <in-unicast-pkts>94</in-unicast-pkts>
      <in-broadcast-pkts>0</in-broadcast-pkts>
      <in-multicast-pkts>0</in-multicast-pkts>
      <in-discards>0</in-discards>
      <in-errors>0</in-errors>
      <in-unknown-protos>0</in-unknown-protos>
      <out-octets>89363</out-octets>
      <out-unicast-pkts>209</out-unicast-pkts>
      <out-broadcast-pkts>0</out-broadcast-pkts>
      <out-multicast-pkts>0</out-multicast-pkts>
      <out-discards>0</out-discards>
      <out-errors>0</out-errors>
    </statistics>
  </interface>
</interfaces>
```

Using the first enclosing method, we will demonstrate how to augment the previous ietf-interfaces YANG module by defining it in the new example module below:


```

module interfaces-provenance-augmented {
  yang-version 1.1;
  namespace "urn:example:interfaces-provenance-augmented";
  prefix ifprov;

  import ietf-interfaces {
    prefix if;
  }
  import ietf-yang-provenance {
    prefix iyangprov;
  }

  description
    "Augments ietf-interfaces with provenance information";

  revision "2025-10-08" {
    description
      "Initial revision of the augment module adding provenance information to ietf-inter
faces.";
  }

  augment "/if:interfaces" {
    leaf interfaces-provenance {
      type iyangprov:provenance-signature;
      description
        "Signature proving provenance of the interface configuration";
    }
  }
}

```

The following tree diagram illustrates the augmentation of the ietf-interfaces module with a provenance-signature at the root container:

```

module: ietf-interfaces
  +--rw interfaces
    +--rw interface* [name]
      |   +--rw name          string
      |   +--rw type          identityref
      |   ...
      +--rw ifprov:interfaces-provenance?  iyangprov:provenance-signature

```

The following example illustrates how a provenance signature can be attached to the root interfaces container to protect the entire set of interface configuration and operational data. This augmentation adds a provenance-signature leaf at the root interfaces container (named "interfaces-provenance" in this case) and produces the following output:

```
<?xml version="1.0" encoding="UTF-8"?>
<interfaces xmlns="urn:ietf:params:xml:ns:yang:ietf-interfaces">
  <interfaces-provenance xmlns="urn:example:interfaces-provenance-augmented">
    0oRRoWnJeGlsBGdlYzIua2V5ASag9lhAvzyFP5HP0nONaqTRxKmSqerrDS6C
    QXJSK+5NdprzQZLf0QsHtAi2pxzbuDJDy9kZoylJTVNaJmMxGTLdm4ktug==
  </interfaces-provenance>
  <interface>
    <name>GigabitEthernet1</name>
    <type xmlns:ianaift="urn:ietf:params:xml:ns:yang:iana-if-type">
      ianaift:ethernetCsmacd</type>
    <admin-status>up</admin-status>
    <oper-status>up</oper-status>
    <last-change>2024-02-03T11:22:41.081+00:00</last-change>
    <if-index>1</if-index>
    <phys-address>0c:00:00:37:d6:00</phys-address>
    <speed>1000000000</speed>
    <statistics>
      <discontinuity-time>2024-02-03T11:20:38+00:00</discontinuity-time>
      <in-octets>8157</in-octets>
      <in-unicast-pkts>94</in-unicast-pkts>
      <in-broadcast-pkts>0</in-broadcast-pkts>
      <in-multicast-pkts>0</in-multicast-pkts>
      <in-discards>0</in-discards>
      <in-errors>0</in-errors>
      <in-unknown-protos>0</in-unknown-protos>
      <out-octets>89363</out-octets>
      <out-unicast-pkts>209</out-unicast-pkts>
      <out-broadcast-pkts>0</out-broadcast-pkts>
      <out-multicast-pkts>0</out-multicast-pkts>
      <out-discards>0</out-discards>
      <out-errors>0</out-errors>
    </statistics>
  </interface>
</interfaces>
```

The second enclosing method shows a notification with the provenance signature included inside the notification envelope. The provenance element is placed immediately before the contents element:

```

<?xml version="1.0" encoding="UTF-8"?>
<envelope xmlns="urn:ietf:params:xml:ns:yang:ietf-yp-notification">
  <event-time>2024-02-03T11:37:25.94Z</event-time>
  <provenance xmlns="urn:ietf:params:xml:ns:yang:ietf-yp-provenance">
    0oRRoWNjeGlsBGdlyZiua2V5ASag9lhAzyJBpvpzI/TirrjckAA29q6Qmf
    u56L8ZhUXXhu0KFcKh1qSRFx2wGR/y+XgKigVHYicC7fp/0AlHSXWiKB2sg==
  </provenance>
  <contents>
    <push-update xmlns="urn:ietf:params:xml:ns:yang:ietf-yang-push">
      <subscription-id>2147483648</subscription-id>
      <datastore-contents>
        <interfaces-state xmlns="urn:ietf:params:xml:ns:yang:ietf-interfaces">
          <interface>
            <name>GigabitEthernet1</name>
            <type xmlns:ianaift="urn:ietf:params:xml:ns:yang:iana-if-type">
              ianaift:ethernetCsmacd</type>
            <admin-status>up</admin-status>
            <oper-status>up</oper-status>
            <last-change>2024-02-03T11:22:41.081+00:00</last-change>
            <if-index>1</if-index>
            <phys-address>0c:00:00:37:d6:00</phys-address>
            <speed>1000000000</speed>
            <statistics>
              <discontinuity-time>2024-02-03T11:20:38+00:00</discontinuity-
time>
              <in-octets>8157</in-octets>
              <in-unicast-pkts>94</in-unicast-pkts>
              <in-broadcast-pkts>0</in-broadcast-pkts>
              <in-multicast-pkts>0</in-multicast-pkts>
              <in-discards>0</in-discards>
              <in-errors>0</in-errors>
              <in-unknown-protos>0</in-unknown-protos>
              <out-octets>89363</out-octets>
              <out-unicast-pkts>209</out-unicast-pkts>
              <out-broadcast-pkts>0</out-broadcast-pkts>
              <out-multicast-pkts>0</out-multicast-pkts>
              <out-discards>0</out-discards>
              <out-errors>0</out-errors>
            </statistics>
          </interface>
        </interfaces-state>
      </datastore-contents>
    </push-update>
  </contents>
</envelope>

```

The third enclosing method, applicable if the instance is to be stored as YANG instance data at rest, by adding the corresponding metadata, would produce a results as shown below:

```
<?xml version="1.0" encoding="UTF-8"?>
<instance-data-set xmlns="urn:ietf:params:xml:ns:yang:ietf-yang-instance-data">
  <name>atRestYANG</name>
  <content-schema></content-schema>
  <revision>
    <date>2024-11-03</date>
    <description>For demos</description>
  </revision>
  <description>Sample for demonstrating provenance signatures</description>
  <contact>diego.r.lopez@telefonica.com</contact>
  <provenance xmlns="urn:ietf:params:xml:ns:yang:ietf-yang-instance-data-provenance">
    0oRRoWnJeG1sBGdlYzIua2V5ASag9lhAWff+fMbfNChKUYZ52UTOBmAlYPFe4
    vlZOLyZeW0CU7/2OutDeMCG28+m3rm58jqLjKbcueKLFq8qFJb4mvPY+Q==
  </provenance>
  <content-data>
    <interfaces-state xmlns="urn:ietf:params:xml:ns:yang:ietf-interfaces">
      <interface>
        <name>GigabitEthernet1</name>
        <type xmlns:ianaift="urn:ietf:params:xml:ns:yang:iana-if-type">
          ianaift:ethernetCsmacd</type>
        <admin-status>up</admin-status>
        <oper-status>up</oper-status>
        <last-change>2024-02-03T11:22:41.081+00:00</last-change>
        <if-index>1</if-index>
        <phys-address>0c:00:00:37:d6:00</phys-address>
        <speed>1000000000</speed>
        <statistics>
          <discontinuity-time>2024-02-03T11:20:38+00:00</discontinuity-time>
          <in-octets>8157</in-octets>
          <in-unicast-pkts>94</in-unicast-pkts>
          <in-broadcast-pkts>0</in-broadcast-pkts>
          <in-multicast-pkts>0</in-multicast-pkts>
          <in-discards>0</in-discards>
          <in-errors>0</in-errors>
          <in-unknown-protos>0</in-unknown-protos>
          <out-octets>89363</out-octets>
          <out-unicast-pkts>209</out-unicast-pkts>
          <out-broadcast-pkts>0</out-broadcast-pkts>
          <out-multicast-pkts>0</out-multicast-pkts>
          <out-discards>0</out-discards>
          <out-errors>0</out-errors>
        </statistics>
      </interface>
    </interfaces-state>
  </content-data>
</instance-data-set>
```

Finally, using the fourth enclosing method, the YANG instance would incorporate the corresponding provenance metadata as an annotation, using the namespace prefix specified in the ietf-yang-provenance-annotation module, as introduced in Section 4.4:

```
<?xml version="1.0" encoding="UTF-8"?>
<interfaces-state xmlns="urn:ietf:params:xml:ns:yang:ietf-interfaces"
  xmlns:ypmd="urn:ietf:params:xml:ns:yang:ietf-yang-annotation-pmd"
  ypmd:provenance=
    "0oRRoWnJjeG1sBGdlYzIua2V5ASag9lhAzen3Bm9AZoyXuetoTB70SzZqKVxeu
    OMW099sm+NXSqCfnqBKfXeuqDNEkuEr+E0XiAso986fbAHQCHbAJM0hw==">
  <interface>
    <name>GigabitEthernet1</name>
    <type xmlns:ianaift="urn:ietf:params:xml:ns:yang:iana-if-type">
      ianaift:ethernetCsmacd</type>
    <admin-status>up</admin-status>
    <oper-status>up</oper-status>
    <last-change>2024-02-03T11:22:41.081+00:00</last-change>
    <if-index>1</if-index>
    <phys-address>0c:00:00:37:d6:00</phys-address>
    <speed>1000000000</speed>
    <statistics>
      <discontinuity-time>2024-02-03T11:20:38+00:00</discontinuity-time>
      <in-octets>8157</in-octets>
      <in-unicast-pkts>94</in-unicast-pkts>
      <in-broadcast-pkts>0</in-broadcast-pkts>
      <in-multicast-pkts>0</in-multicast-pkts>
      <in-discards>0</in-discards>
      <in-errors>0</in-errors>
      <in-unknown-protos>0</in-unknown-protos>
      <out-octets>89363</out-octets>
      <out-unicast-pkts>209</out-unicast-pkts>
      <out-broadcast-pkts>0</out-broadcast-pkts>
      <out-multicast-pkts>0</out-multicast-pkts>
      <out-discards>0</out-discards>
      <out-errors>0</out-errors>
    </statistics>
  </interface>
</interfaces>
```

JSON

Let us consider the following YANG instance, corresponding to the same monitoring interface statement, with JSON serialization:

```
{
  "ietf-interfaces:interfaces": {
    "interface": [
      {
        "name": "GigabitEthernet1",
        "type": "ianaift:ethernetCsmacd",
        "admin-status": "up",
        "oper-status": "up",
        "last-change": "2024-02-03T11:22:41.081+00:00",
        "if-index": 1,
        "phys-address": "0c:00:00:37:d6:00",
        "speed": 1000000000,
        "statistics": {
          "discontinuity-time": "2024-02-03T11:20:38+00:00",
          "in-octets": 8157,
          "in-unicast-pkts": 94,
          "in-broadcast-pkts": 0,
          "in-multicast-pkts": 0,
          "in-discards": 0,
          "in-errors": 0,
          "in-unknown-protos": 0,
          "out-octets": 89363,
          "out-unicast-pkts": 209,
          "out-broadcast-pkts": 0,
          "out-multicast-pkts": 0,
          "out-discards": 0,
          "out-errors": 0
        }
      }
    ]
  }
}
```

Applying the first enclosing method, a provenance-signature leaf at the top element (named "interfaces-provenance" in this case) would be included following the augmentation module previously defined for the XML example. This will produce the following output:

```
{
  "ietf-interfaces:interfaces": {
    "interface": [
      {
        "name": "GigabitEthernet1",
        "type": "ianaift:ethernetCsmacd",
        "admin-status": "up",
        "oper-status": "up",
        "last-change": "2024-02-03T11:22:41.081+00:00",
        "if-index": 1,
        "phys-address": "0c:00:00:37:d6:00",
        "speed": 1000000000,
        "statistics": {
          "discontinuity-time": "2024-02-03T11:20:38+00:00",
          "in-octets": 8157,
          "in-unicast-pkts": 94,
          "in-broadcast-pkts": 0,
          "in-multicast-pkts": 0,
          "in-discards": 0,
          "in-errors": 0,
          "in-unknown-protos": 0,
          "out-octets": 89363,
          "out-unicast-pkts": 209,
          "out-broadcast-pkts": 0,
          "out-multicast-pkts": 0,
          "out-discards": 0,
          "out-errors": 0
        }
      }
    ],
    "interfaces-provenance-augmented:interfaces-provenance":
      "0oRRoWnJeGlSBGdlYzIua2V5ASag9lhAvzyFP5HP0nONaqTRxKmSqerrDS6C
      QXJSK+5NdprzQZLf0QsHtAi2pxzbuDJDy9kZoylJTVNaJmMxGTLdm4ktug=="
  }
}
```

The second enclosing method would translate into a notification including the "provenance" element as follows:

```

{
  "ietf-yp-notification:envelope" : {
    "event-time" : "2013-12-21T00:01:00Z",
    "ietf-yp-provenance:provenance":
      "0oRRoWNjeGlsBGdlyzIua2V5ASag9lhAiKEKLQKJT12LsNgxt8WllEI65lyi
      E/m12drCfl+wh7T61cTYhFGdEeX8A5F0vmUWROZebq/VVFewUZeVYGZBOQ==",
    "contents": {
      "ietf-yang-push:push-update": {
        "subscription-id": 2147483648,
        "datastore-contents": {
          "ietf-interfaces:interfaces-state": {
            "interface": [ {
              "name": "GigabitEthernet1",
              "type": "ianaift:ethernetCsmacd",
              "admin-status": "up",
              "oper-status": "up",
              "last-change": "2024-02-03T11:22:41.081+00:00",
              "if-index": 1,
              "phys-address": "0c:00:00:37:d6:00",
              "speed": 1000000000,
              "statistics": {
                "discontinuity-time": "2024-02-03T11:20:38+00:00",
                "in-octets": 8157,
                "in-unicast-pkts": 94,
                "in-broadcast-pkts": 0,
                "in-multicast-pkts": 0,
                "in-discards": 0,
                "in-errors": 0,
                "in-unknown-protos": 0,
                "out-octets": 89363,
                "out-unicast-pkts": 209,
                "out-broadcast-pkts": 0,
                "out-multicast-pkts": 0,
                "out-discards": 0,
                "out-errors": 0
              }
            }
          ]
        }
      }
    }
  }
}

```

The third enclosing method, applicable if the instance is to be stored as YANG instance data at rest, by adding the corresponding metadata, would produce a results as shown below:


```

{
  "ietf-yang-instance-data:instance-data-set" : {
    "name" : "interfaces-labTID-status",
    "contact" : "sofia.garciarincon.practicas@telefonica.com",
    "timestamp" : "Thu Jul 18 11:42:06 CEST 2024",
    "ietf-yang-instance-data-provenance:provenance" :
      "0oRRowNjeGlsBGdlyzIua2V5ASag9lhAmop/c7wMcjRmiSPVy65F/N6O21dsG
      kjGQjIDRizhu3WMwi9Je+VUf5sqwlhSwQCdv5u7mRXa6Pd9dhCwdxdRCA==",
    "content-data" : {
      "ietf-interfaces:interfaces": {
        "interface": [
          {
            "name": "GigabitEthernet1",
            "iana-if-type:type": "ianaift:ethernetCsmacd",
            "admin-status": "up",
            "oper-status": "up",
            "last-change": "2024-02-03T11:22:41.081+00:00",
            "if-index": 1,
            "phys-address": "0c:00:00:37:d6:00",
            "speed": 1000000000,
            "statistics": {
              "discontinuity-time": "2024-02-03T11:20:38+00:00",
              "in-octets": 8157,
              "in-unicast-pkts": 94,
              "in-broadcast-pkts": 0,
              "in-multicast-pkts": 0,
              "in-discards": 0,
              "in-errors": 0,
              "in-unknown-protos": 0,
              "out-octets": 89363,
              "out-unicast-pkts": 209,
              "out-broadcast-pkts": 0,
              "out-multicast-pkts": 0,
              "out-discards": 0,
              "out-errors": 0
            }
          }
        ]
      }
    }
  }
}

```

Finally, using the fourth enclosing method, the YANG instance would incorporate the corresponding provenance metadata as an annotation, using the namespace prefix specified in the yang-provenance-metadata module, as introduced in Section 4.4, and the recommendations in section 5.2.3 of [RFC7952]:

```

{
  "ietf-interfaces:interfaces" : {
    "@": {
      "ypmd:provenance": "0oRRoWNjeG1sBGdlYzIua2V5ASag9lhAM/Dx3HVc4GL91jmuU5nWgcmOPPVpARL
JkWo5wwQYvGFJpKMXTkjAtArPp8v6Sl1ZDlqHimKMhAoHLMHVxBtrcA=="
    },
    "interface" : [
      {
        "name" : "GigabitEthernet1",
        "iana-if-type:type" : "ianaift:ethernetCsmacd",
        "admin-status" : "up",
        "oper-status" : "up",
        "last-change" : "2024-02-03T11:22:41.081+00:00",
        "if-index" : 1,
        "phys-address" : "0c:00:00:37:d6:00",
        "speed" : 1000000000,
        "statistics" : {
          "discontinuity-time" : "2024-02-03T11:20:38+00:00",
          "in-octets" : 8157,
          "in-unicast-pkts" : 94,
          "in-broadcast-pkts" : 0,
          "in-multicast-pkts" : 0,
          "in-discards" : 0,
          "in-errors" : 0,
          "in-unknown-protos" : 0,
          "out-octets" : 89363,
          "out-unicast-pkts" : 209,
          "out-broadcast-pkts" : 0,
          "out-multicast-pkts" : 0,
          "out-discards" : 0,
          "out-errors" : 0
        }
      }
    ]
  }
}

```

CBOR

TBD, as the reference implementation evolves.

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Thanks to Sofia Garcia (UC3M, sgarciarincon01@gmail.com) for being instrumental in demonstrating the feasibility of the proposed approach, providing a first proof of concept of YANG provenance signatures.

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