
Stream: Internet Engineering Task Force (IETF)
RFC: [9684](#)
Category: Standards Track
Published: October 2024
ISSN: 2070-1721
Authors: H. Birkholz M. Eckel S. Bhandari E. Voit B. Sulzen L. Xia
Fraunhofer SIT Fraunhofer SIT ThoughtSpot Cisco Cisco Huawei
T. Laffey G. Fedorkow
HPE Juniper

RFC 9684

A YANG Data Model for Challenge-Response-Based Remote Attestation (CHARRA) Procedures Using Trusted Platform Modules (TPMs)

Abstract

This document defines the YANG Remote Procedure Calls (RPCs) and configuration nodes that are required to retrieve attestation evidence about integrity measurements from a device, following the operational context defined in RFC 9683 "TPM-based Network Device Remote Integrity Verification". Complementary measurement logs originating from one or more Roots of Trust for Measurement (RTMs) are also provided by the YANG RPCs. The module defined requires at least one TPM 1.2 or TPM 2.0 as well as a corresponding TPM Software Stack (TSS), or equivalent hardware implementations that include the protected capabilities as provided by TPMs as well as a corresponding software stack, included in the device components of the composite device the YANG server is running on.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at <https://www.rfc-editor.org/info/rfc9684>.

Copyright Notice

Copyright (c) 2024 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Revised BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Revised BSD License.

Table of Contents

1. Introduction	2
1.1. Requirements Notation	3
2. The YANG Module for Basic Remote Attestation Procedures	3
2.1. YANG Modules	3
2.1.1. ietf-tpm-remote-attestation	3
2.1.2. ietf-tcg-algs	31
3. IANA Considerations	44
4. Security Considerations	45
5. References	46
5.1. Normative References	46
5.2. Informative References	50
Appendix A. Integrity Measurement Architecture (IMA)	50
Appendix B. IMA for Network Equipment Boot Logs	51
Authors' Addresses	52

1. Introduction

This document is based on the general terminology defined in Remote Attestation procedureS (RATS) architecture [RFC9334] and uses the operational context defined in [RFC9683] as well as the interaction model and information elements defined in [RATS-Interaction-Models]. The

currently supported hardware security modules (HSMs) are the Trusted Platform Modules (TPMs) [TPM1.2] [TPM2.0] as specified by the Trusted Computing Group (TCG). One TPM, or multiple TPMs in the case of a composite device, is required in order to use the YANG module defined in this document. Each TPM is used as a Root of Trust for Storage (RTS) in order to store system security measurement Evidence. And each TPM is used as a Root of Trust for Reporting (RTR) in order to retrieve attestation Evidence. This is done by using a YANG RPC to request a quote that exposes a rolling hash of the security measurements held internally within the TPM.

Specific terms imported from [RFC9334] and used in this document include Attester, composite device, and Evidence.

Specific terms imported from [TPM2.0-Key] and used in this document include Endorsement Key (EK), Initial Attestation Key (IAK), Attestation Identity Key (AIK), and Local Attestation Key (LAK).

1.1. Requirements Notation

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. The YANG Module for Basic Remote Attestation Procedures

One or more TPMs **MUST** be embedded in a composite device that provides attestation Evidence via the YANG module defined in this document. The ietf-tpm-remote-attestation YANG module enables a composite device to take on the role of an Attester, in accordance with the RATS architecture [RFC9334] and the corresponding challenge-response interaction model defined in [RATS-Interaction-Models]. A fresh nonce with an appropriate amount of entropy [NIST-915121] **MUST** be supplied by the YANG client in order to enable a proof-of-freshness with respect to the attestation Evidence provided by the Attester running the YANG datastore. Further, this nonce is used to prevent replay attacks. The method for communicating the relationship of each individual TPM to the specific measured component within the composite device is out of the scope of this document.

2.1. YANG Modules

In this section, the two YANG modules are defined.

2.1.1. ietf-tpm-remote-attestation

This YANG module imports modules from [RFC6991] with prefix 'yang', [RFC8348] with prefix 'hw', [RFC9642] with prefix 'ks', and ietf-tcg-algs.yang Section 2.1.2.3 with prefix 'taa'. Additionally, references are made to [RFC6933], [TPM1.2-Commands], [TPM2.0-Arch], [TPM2.0-Structures], [TPM2.0-Key], [TPM1.2-Structures], [BIOS-Log], [BIOS-Log-Event-Type], and [CEL], as well as Appendix B.

2.1.1.1. Features

This module supports the following features:

'mtpm': Indicates that multiple TPMs on the device can support remote attestation. For example, this feature could be used in cases where multiple line cards are present, each with its own TPM.

'bios': Indicates that the device supports the retrieval of BIOS and Unified Extensible Firmware Interface (UEFI) event logs [[BIOS-Log](#)].

'ima': Indicates that the device supports the retrieval of event logs from the Linux Integrity Measurement Architecture (IMA, see [Appendix A](#)).

'netequip_boot': Indicates that the device supports the retrieval of netequip boot event logs. See [Appendixes A and B](#).

2.1.1.2. Identities

This module supports the following types of attestation event logs: 'bios', 'ima', and 'netequip_boot'.

2.1.1.3. Remote Procedure Calls (RPCs)

In the following sections, RPCs for attestation procedures for both TPM 1.2 and TPM 2.0 are defined.

2.1.1.3.1. tpm12-challenge-response-attestation

This RPC allows a Verifier to request signed TPM PCRs (*TPM Quote* operation) from a cryptoprocessor compliant with TPM 1.2. Where the feature 'mtpm' is active, and one or more 'certificate-name' is not provided, all cryptoprocessors compliant with TPM 1.2 will respond. The YANG tree diagram of this RPC is as follows:

```

+---x tpm12-challenge-response-attestation {taa:tpm12}?
  +---w input
    | +---w tpm12-attestation-challenge
    |   +---w pcr-index*          pcr
    |   +---w nonce-value        binary
    |   +---w certificate-name*   certificate-name-ref
    |                               {tpm:mtpm}?
  +--ro output
    +--ro tpm12-attestation-response* []
      +--ro certificate-name   certificate-name-ref
      +--ro up-time?          uint32
      +--ro TPM_QUOTE2?      binary

```

2.1.1.3.2. tpm20-challenge-response-attestation

This RPC allows a Verifier to request signed TPM PCRs (*TPM Quote* operation) from a cryptoprocessor compliant with TPM 2.0. Where the feature 'mtpm' is active, and one or more 'certificate-name' is not provided, all cryptoprocessors compliant with TPM 2.0 will respond. The YANG tree diagram of this RPC is as follows:

```

+---x tpm20-challenge-response-attestation {taa:tpm20}?
  +---w input
  |   +---w tpm20-attestation-challenge
  |   |   +---w nonce-value          binary
  |   |   +---w tpm20-pcr-selection* []
  |   |   |   +---w tpm20-hash-algo?  identityref
  |   |   |   +---w pcr-index*       pcr
  |   |   +---w certificate-name*    certificate-name-ref
  |   |   |   {tpm:mtpm}?
  +---ro output
  +---ro tpm20-attestation-response* []
  +---ro certificate-name            certificate-name-ref
  +---ro TPMS_QUOTE_INFO             binary
  +---ro quote-signature?           binary
  +---ro up-time?                   uint32
  +---ro unsigned-pcr-values* []
  |   +---ro tpm20-hash-algo?       identityref
  |   +---ro pcr-values* [pcr-index]
  |   |   +---ro pcr-index         pcr
  |   |   +---ro pcr-value?       binary

```

An example of an RPC challenge requesting PCRs 0-7 from a SHA-256 bank could look like the following:

```

<rpc message-id="101"
  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <tpm20-attestation-challenge
    xmlns="urn:ietf:params:xml:ns:yang:ietf-tpm-remote-attestation">
    <certificate-name>
      (identifier of a TPM signature key with which the Attester is
      supposed to sign the attestation data)
    </certificate-name>
    <nonce>
      0xe041307208d9f78f5b1bbeed19e2d152ad49de2fc5a7d8dbf769f6b8ffdeab9
    </nonce>
    <tpm20-pcr-selection>
      <tpm20-hash-algo
        xmlns="urn:ietf:params:xml:ns:yang:ietf-tcg-algs">
        TPM_ALG_SHA256
      </tpm20-hash-algo>
      <pcr-index>0</pcr-index>
      <pcr-index>1</pcr-index>
      <pcr-index>2</pcr-index>
      <pcr-index>3</pcr-index>
      <pcr-index>4</pcr-index>
      <pcr-index>5</pcr-index>
      <pcr-index>6</pcr-index>
      <pcr-index>7</pcr-index>
    </tpm20-pcr-selection>
  </tpm20-attestation-challenge>
</rpc>

```

A successful response could be formatted as follows:

```

<rpc-reply message-id="101"
  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <tpm20-attestation-response
    xmlns="urn:ietf:params:xml:ns:yang:ietf-tpm-remote-attestation">
    <certificate-name
      xmlns="urn:ietf:params:xml:ns:yang:ietf-keystore">
      (instance of certificate name in the keystore)
    </certificate-name>
    <attestation-data>
      (raw attestation data, i.e., the TPM quote; this includes,
      among other information, a composite digest of requested PCRs,
      the nonce, and TPM 2.0 clock information.)
    </attestation-data>
    <quote-signature>
      (signature over attestation-data using the TPM key
      identified by sig-key-id)
    </quote-signature>
  </tpm20-attestation-response>
</rpc-reply>

```

2.1.1.4. log-retrieval

This RPC allows a Verifier to acquire the Evidence that was extended into specific TPM PCRs. The YANG tree diagram of this RPC is as follows:

```

+---x log-retrieval
  +---w input
  | +---w log-type          identityref
  | +---w log-selector* []
  |   +---w name*          string
  |   +---w (index-type)?
  |     +---:(last-entry)
  |       | +---w last-entry-value?  binary
  |       | +---:(index)
  |       | | +---w last-index-number? uint64
  |       | +---:(timestamp)
  |       | | +---w timestamp?       yang:date-and-time
  |       | +---w log-entry-quantity? uint16
  | +---ro output
  |   +---ro system-event-logs
  |     +---ro node-data* []
  |       +---ro name?          string
  |       +---ro up-time?       uint32
  |       +---ro log-result
  |         +---ro (attested_event_log_type)
  |           +---:(bios) {bios}?
  |             +---ro bios-event-logs
  |               +---ro bios-event-entry* [event-number]
  |                 +---ro event-number    uint32
  |                 +---ro event-type?     uint32
  |                 +---ro pcr-index?      pcr
  |                 +---ro digest-list* []
  |                   | +---ro hash-algo?  identityref
  |                   | +---ro digest*    binary
  |                   +---ro event-size?   uint32
  |                   +---ro event-data*   binary
  |           +---:(ima) {ima}?
  |             +---ro ima-event-logs
  |               +---ro ima-event-entry* [event-number]
  |                 +---ro event-number    uint64
  |                 +---ro ima-template?   string
  |                 +---ro filename-hint?  string
  |                 +---ro filedata-hash?  binary
  |                 +---ro filedata-hash-algorithm? string
  |                 +---ro template-hash-algorithm? string
  |                 +---ro template-hash?  binary
  |                 +---ro pcr-index?      pcr
  |                 +---ro signature?      binary
  |           +---:(netequip_boot) {netequip_boot}?
  |             +---ro boot-event-logs
  |               +---ro boot-event-entry* [event-number]
  |                 +---ro event-number    uint64
  |                 +---ro ima-template?   string
  |                 +---ro filename-hint?  string
  |                 +---ro filedata-hash?  binary
  |                 +---ro filedata-hash-algorithm? string
  |                 +---ro template-hash-algorithm? string
  |                 +---ro template-hash?  binary
  |                 +---ro pcr-index?      pcr
  |                 +---ro signature?      binary

```

2.1.1.5. Data Nodes

This section provides a high-level description of the data nodes that contain the configuration and operational objects within the YANG data model. For more details, please see the YANG module itself in [Figure 1](#).

Container 'rats-support-structures': This houses the set of information relating to remote attestation for a device. This includes specific device TPM(s), the compute nodes (such as line cards) on which the TPM(s) reside, and the algorithms supported across the platform.

Container 'tpms': This provides configuration and operational details for each supported TPM, including the tpm-firmware-version, PCRs that may be quoted, certificates that are associated with that TPM, and the current operational status. Of note are the certificates that are associated with that TPM. As a certificate is associated with a particular TPM Attestation Key, knowledge of the certificate allows a specific TPM to be identified.

```

+--rw tpms
  +--rw tpm* [name]
    +--rw name string
    +--ro hardware-based boolean
    +--ro physical-index? int32 {hw:entity-mib}?
    +--ro path? string
    +--ro compute-node compute-node-ref {tpm:mtpm}?
    +--ro manufacturer? string
    +--rw firmware-version identityref
    +--rw tpm12-hash-algo? identityref {taa:tpm12}?
    +--rw tpm12-pcrs* pcr
    +--rw tpm20-pcr-bank* [tpm20-hash-algo] {taa:tpm20}?
    | +--rw tpm20-hash-algo identityref
    | +--rw pcr-index* tpm:pcr
    +--ro status enumeration
    +--rw certificates
      +--rw certificate* [name]
        +--rw name string
        +--rw keystore-ref? leafref {ks:asymmetric-keys}?
        +--rw type? enumeration
  
```

Container 'attester-supported-algos': This identifies which TCG hash algorithms are available for use on the Attesting platform. An operator will use this information to limit algorithms available for use by RPCs to just a desired set from the universe of all hash algorithms allowed by the TCG.

```

+--rw attester-supported-algos
  +--rw tpm12-asymmetric-signing* identityref {taa:tpm12}?
  +--rw tpm12-hash* identityref {taa:tpm12}?
  +--rw tpm20-asymmetric-signing* identityref {taa:tpm20}?
  +--rw tpm20-hash* identityref {taa:tpm20}?
  
```

Container 'compute-nodes': When there is more than one TPM supported, this container maintains the set of information related to the compute node associated with a specific TPM. This allows each specific TPM to identify to which 'compute-node' it belongs.

```
+-rw compute-nodes {tpm:mtpm}?
  +--ro compute-node* [node-id]
    +--ro node-id                string
    +--ro node-physical-index?   int32 {hw:entity-mib}?
    +--ro node-name?             string
    +--ro node-location?         string
```

2.1.1.6. YANG Module

```
<CODE BEGINS> file "ietf-tpm-remote-attestation@2024-10-22.yang"

module ietf-tpm-remote-attestation {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang"
    + ":ietf-tpm-remote-attestation";
  prefix tpm;

  import ietf-yang-types {
    prefix yang;
  }
  import ietf-hardware {
    prefix hw;
  }
  import ietf-keystore {
    prefix ks;
  }
  import ietf-tcg-algs {
    prefix taa;
  }

  organization
    "IETF RATS (Remote ATtestation procedures) Working Group";
  contact
    "WG Web : <https://datatracker.ietf.org/wg/rats/>
    WG List : <mailto:rats@ietf.org>
    Author : Eric Voit <evoit@cisco.com>
    Author : Henk Birkholz <henk.birkholz@ietf.contact>
    Author : Michael Eckel <michael.eckel@sit.fraunhofer.de>
    Author : Shwetha Bhandari <shwetha.bhandari@thoughtspot.com>
    Author : Bill Sulzen <bsulzen@cisco.com>
    Author : Liang Xia (Frank) <frank.xialiang@huawei.com>
    Author : Tom Laffey <tom.laffey@hpe.com>
    Author : Guy Fedorkow <gfedorkow@juniper.net>";
  description
    "A YANG module to enable remote attestation procedures based
    on TPM 1.2 and TPM 2.0 using a challenge-response
    interaction model and the Quote primitive operations defined
    by TPM 1.2 and TPM 2.0.

    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.

    Copyright (c) 2024 IETF Trust and the persons identified as
    authors of the code. All rights reserved.

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

    This version of this YANG module is part of RFC 9684; see the
```

```
    RFC itself for full legal notices."};

revision 2024-10-22 {
  description
    "Initial version";
  reference
    "RFC 9684: A YANG Data Model for Challenge-Response-Based
    Remote Attestation (CHARRA) Procedures Using Trusted Platform
    Modules (TPMs)";
}

/*****
/*  Features  */
*****/

feature mtpm {
  description
    "The device supports the remote attestation of multiple
    TPM-based cryptoprocessors.";
}

feature bios {
  description
    "The device supports the BIOS logs.";
  reference
    "BIOS-Log:
    TCG PC Client Platform Firmware Profile Specification,
    https://trustedcomputinggroup.org/wp-content/uploads/
    PC-ClientSpecific_Platform_Profile_for_TPM_2p0_Systems_v51.pdf
    Section 9.4.5.2";
}

feature ima {
  description
    "The device supports Integrity Measurement Architecture logs.
    Many variants of IMA logs exist in the deployment. Each
    encodes the log entry contents as the specific measurements
    that get hashed into a PCRs as Evidence. See the reference
    below for one example of such an encoding.";
  reference
    "CEL:
    Canonical Event Log Format,
    https://www.trustedcomputinggroup.org/wp-content/uploads/
    TCG_IWG_CEL_v1_r0p41_pub.pdf, Section 5.1.6";
}

feature netequip_boot {
  description
    "The device supports the netequip_boot logs.";
  reference
    "RFC 9684: A YANG Data Model for Challenge-Response-Based
    Remote Attestation (CHARRA) Procedures Using Trusted Platform
    Modules (TPMs), Appendix B";
}

/*****
/*  Typedefs  */
*****/
```

```
typedef pcr {
  type uint8 {
    range "0..31";
  }
  description
    "Valid index number for a PCR. A PCR index compliant with
    TPM 2.0 extends from 0-31. At this time, a typical TPM would
    have no more than 32 PCRs.";
}

typedef compute-node-ref {
  type leafref {
    path "/tpm:rats-support-structures/tpm:compute-nodes"
      + "/tpm:compute-node/tpm:node-id";
  }
  description
    "This type is used to reference a hardware node. Note that an
    implementer might include an alternative leafref pointing to a
    different YANG module node specifying hardware structures.";
}

typedef certificate-name-ref {
  type leafref {
    path "/tpm:rats-support-structures/tpm:tpms/tpm:tpm"
      + "/tpm:certificates/tpm:certificate/tpm:name";
  }
  description
    "A type that allows identification of a TPM-based
    certificate.";
}

/*****
/* Identities */
*****/

identity attested_event_log_type {
  description
    "Base identity allowing categorization of the reasons why an
    attested measurement has been taken on an Attester.";
}

identity ima {
  base attested_event_log_type;
  description
    "An event type recorded in IMA.";
}

identity bios {
  base attested_event_log_type;
  description
    "An event type associated with BIOS/UEFI.";
}

identity netequip_boot {
  base attested_event_log_type;
  description
    "An event type associated with Network Equipment Boot.";
```

```

}

/*****
/* Groupings */
*****/

grouping tpm20-hash-algo {
  description
    "The cryptographic algorithm used to hash the PCRs compliant
    with TPM 2.0. This must be from the list of platform-
    supported options.";
  leaf tpm20-hash-algo {
    type identityref {
      base taa:hash;
    }
    must '. = /tpm:rats-support-structures'
      + '/tpm:attester-supported-algos/tpm:tpm20-hash' {
      error-message "This platform does not support "
        + "tpm20-hash-algo";
    }
    description
      "The hash scheme that is used to hash a PCR compliant with
      TPM 2.0. This must be one of those supported by a platform.
      Where this object does not appear, the default value of
      'taa:TPM_ALG_SHA256' will apply.";
  }
}

grouping tpm12-hash-algo {
  description
    "The cryptographic algorithm used to hash the PCRs compliant
    with TPM 1.2.";
  leaf tpm12-hash-algo {
    type identityref {
      base taa:hash;
    }
    must '. = /tpm:rats-support-structures'
      + '/tpm:attester-supported-algos/tpm:tpm12-hash' {
      error-message "This platform does not support "
        + "tpm12-hash-algo";
    }
    description
      "The hash scheme that is used to hash a PCR compliant with
      TPM 1.2. This MUST be one of those supported by a platform.
      Where this object does not appear, the default value of
      'taa:TPM_ALG_SHA1' will apply.";
  }
}

grouping nonce {
  description
    "A random number intended to guarantee freshness and for use
    as part of a replay-detection mechanism.";
  leaf nonce-value {
    type binary;
    mandatory true;
    description
      "A cryptographically generated random number that should

```

not be predictable prior to its issuance from a random number generation function. The random number MUST be derived from an entropy source external to the Attester.

Note that a nonce sent into a TPM will typically be 160 or 256 binary digits long. (This is 20 or 32 bytes.) So if fewer binary digits are sent, this nonce object will be padded with leading zeros within Quotes returned from the TPM. Additionally, if more bytes are sent, the nonce will be trimmed to the most significant binary digits.";

```

    }
  }
  grouping tpm12-pcr-selection {
    description
      "A Verifier can request one or more PCR values using its
      individually created Attestation Key Certificate (AC).
      The corresponding selection filter is represented in this
      grouping.";
    leaf-list pcr-index {
      type pcr;
      description
        "The numbers/indexes of the PCRs. In addition, any selection
        of PCRs MUST verify that the set of PCRs requested are a
        subset of the set of PCRs exposed in the leaf-list
        /tpm:rats-support-structures
        /tpm:tpms/tpm:tpm[name=current()]/tpm:tpm12-pcrs";
    }
  }
  grouping tpm20-pcr-selection {
    description
      "A Verifier can acquire one or more PCR values, which are
      hashed together in a TPM2B_DIGEST coming from the TPM2.
      The selection list of desired PCRs and the hash algorithm
      is represented in this grouping.";
    list tpm20-pcr-selection {
      unique "tpm20-hash-algo";
      description
        "Specifies the list of PCRs and hash algorithms that can be
        returned within a TPM2B_DIGEST.";
      reference
        "TPM2.0-Structures:
        Trusted Platform Module Library Part 2: Structures
        https://www.trustedcomputinggroup.org/wp-content/uploads/
        TPM-Rev-2.0-Part-2-Structures-01.38.pdf, Section 10.9.7";
      uses tpm20-hash-algo;
      leaf-list pcr-index {
        type pcr;
        description
          "The numbers of the PCRs that which are being tracked
          with a hash based on the tpm20-hash-algo. In addition,
          any selection of PCRs MUST verify that the set of PCRs
          requested are a subset the set of PCR indexes selected
          are available for that specific TPM.";
      }
    }
  }
}

```

```
grouping certificate-name-ref {
  description
    "Identifies a certificate in a keystore.";
  leaf certificate-name {
    type certificate-name-ref;
    mandatory true;
    description
      "Identifies a certificate in a keystore.";
  }
}

grouping tpm-name {
  description
    "A unique TPM on a device.";
  leaf name {
    type string;
    description
      "Unique system-generated name for a TPM on a device.";
  }
}

grouping node-uptime {
  description
    "Uptime in seconds of the node.";
  leaf up-time {
    type uint32;
    description
      "Uptime in seconds of this node reporting its data.";
  }
}

grouping tpm12-attestation {
  description
    "Contains an instance of cryptoprocessor measurements signed
    according to TPM 1.2. It is supplemented by unsigned
    Attester information.";
  uses node-uptime;
  leaf pcr-data {
    type binary;
    description
      "The value created and signed for the quote
      (type TPM_PCR_INFO_SHORT), i.e., the 'pcrData' part of
      a TPM1.2 Quote2 operation result.";
    reference
      "TPM1.2-Commands:
      TPM Main Part 3 Commands, Rev116,
      https://trustedcomputinggroup.org/wp-content/uploads/TPM-Main-Part-3-Commands\_v1.2\_rev116\_01032011.pdf,
      Section 16.5";
  }
  leaf version-info {
    type binary;
    description
      "The version info (type TPM_CAP_VERSION_INFO),
      i.e., the 'versionInfo' part of a TPM1.2 Quote2
      operation result.";
    reference
  }
}
```

```

    "TPM1.2-Commands:
      TPM Main Part 3 Commands, Rev116,
      https://trustedcomputinggroup.org/wp-content/uploads
      /TPM-Main-Part-3-Commands_v1.2_rev116_01032011.pdf,
      Section 16.5";
  }
  leaf sig {
    type binary;
    description
      "The signed data blob, i.e., the signature,
      i.e., the 'sig' part of a TPM1.2 Quote2 operation
      result.";
    reference
      "TPM1.2-Commands:
      TPM Main Part 3 Commands, Rev116,
      https://trustedcomputinggroup.org/wp-content/uploads
      /TPM-Main-Part-3-Commands_v1.2_rev116_01032011.pdf,
      Section 16.5";
  }
}

grouping tpm20-attestation {
  description
    "Contains an instance of cryptoprocessor measurements signed
    according to TPM 2.0. It is supplemented by unsigned
    Attester information.";
  leaf quote-data {
    type binary;
    mandatory true;
    description
      "A hash of the latest PCR values (and the hash algorithm
      used) that have been returned from an Attester for the
      selected PCRs and hash algorithms.";
    reference
      "TPM2.0-Structures:
      TPM Main Part 2 TPM Structures, Rev116,
      https://www.trustedcomputinggroup.org/wp-content/uploads/
      TPM-Rev-2.0-Part-2-Structures-01.38.pdf, Section 10.12.1";
  }
  leaf quote-signature {
    type binary;
    description
      "Quote signature returned by TPM Quote. The signature was
      generated using the key associated with the
      certificate 'name'.";
    reference
      "TPM2.0-Structures:
      TPM Main Part 2 TPM Structures, Rev116,
      https://www.trustedcomputinggroup.org/wp-content/uploads/
      TPM-Rev-2.0-Part-2-Structures-01.38.pdf, Section 11.2.1";
  }
  uses node-uptime;
  list unsigned-pcr-values {
    description
      "PCR values in each PCR bank. This might appear redundant
      with the TPM2B_DIGEST, but that digest is calculated across
      multiple PCRs. Having to verify across multiple PCRs does
      not necessarily make it easy for a Verifier to appraise just

```

the minimum set of PCR information that has changed since the last received TPM2B_DIGEST. Put another way, why should a Verifier reconstruct the proper value of all PCR Quotes when only a single PCR has changed?

To help this happen, if the Attester does know specific PCR values, the Attester can provide these individual values via 'unsigned-pcr-values'. By comparing this information to what has previously been validated, it is possible for a Verifier to confirm the Attester's signature while eliminating significant processing. Note that there should never be a result where an unsigned PCR value differs from what may be reconstructed from within the PCR quote and the event logs.

If there is a difference, a signed result that has been verified from retrieved logs is considered definitive.";

```

uses tpm20-hash-algo;
list pcr-values {
  key "pcr-index";
  description
    "List of one PCR bank.";
  leaf pcr-index {
    type pcr;
    description
      "PCR index number.";
  }
  leaf pcr-value {
    type binary;
    description
      "PCR value.";
    reference
      "TPM2.0-Structures:
      TPM Main Part 2 TPM Structures, Rev116,
      https://www.trustedcomputinggroup.org/wp-content/
      uploads/TPM-Rev-2.0-Part-2-Structures-01.38.pdf,
      Section 10.9.7";
  }
}
}
}

grouping log-identifier {
  description
    "Identifier for type of log to be retrieved.";
  leaf log-type {
    type identityref {
      base attested_event_log_type;
    }
    mandatory true;
    description
      "The corresponding identity of the measurement log type.";
  }
}

grouping boot-event-log {
  description
    "Defines a specific instance of an event log entry
    and corresponding to the information used to
    extend the PCR.";
}

```

```
leaf event-number {
  type uint32;
  description
    "Unique event number of this event, which monotonically
    increases within a given event log. The maximum event
    number should not be reached, nor is wrapping back to
    an earlier number supported.";
}
leaf event-type {
  type uint32;
  description
    "BIOS log event type.";
  reference
    "BIOS-Log-Event-Type:
    TCG PC Client Platform Firmware Profile Specification,
    https://trustedcomputinggroup.org/wp-content/uploads/
    TCG_PCClient_PFP_r1p05_v23_pub.pdf, Section 10.4.1";
}
leaf pcr-index {
  type pcr;
  description
    "Defines the PCR index that this event extended.";
}
list digest-list {
  description
    "Hash of event data.";
  leaf hash-algo {
    type identityref {
      base taa:hash;
    }
    description
      "The hash scheme that is used to compress the event data in
      each of the leaf-list digest items.";
  }
  leaf-list digest {
    type binary;
    description
      "The hash of the event data using the algorithm of the
      'hash-algo' against 'event data'.";
  }
}
leaf event-size {
  type uint32;
  description
    "Size of the event data.";
}
leaf-list event-data {
  type binary;
  description
    "The event data. This is a binary structure
    of size 'event-size'. For more on what
    might be recorded within this object
    see BIOS-Log, Section 9, which details
    viable events that might be recorded.";
  reference
    "BIOS-Log:
    TCG PC Client Platform Firmware Profile Specification,
    https://trustedcomputinggroup.org/wp-content/uploads/
```

```
        PC-ClientSpecific_Platform_Profile_for_TPM_2p0_Systems_
        v51.pdf, Section 9";
    }
}

grouping bios-event-log {
    description
        "Measurement log created by the BIOS/UEFI.";
    list bios-event-entry {
        key "event-number";
        description
            "Ordered list of the TCG-described event log
            that extended the PCRs in the order they
            were logged.";
        uses boot-event-log;
    }
}

grouping ima-event {
    description
        "Defines a hash log extend event for IMA measurements.";
    reference
        "CEL:
        Canonical Event Log Format,
        https://www.trustedcomputinggroup.org/wp-content/uploads/
        TCG_IWG_CEL_v1_r0p41_pub.pdf, Section 4.3";
    leaf event-number {
        type uint64;
        description
            "Unique event number of this event, which monotonically
            increases. The maximum event number should not be
            reached, nor is wrapping back to an earlier number
            supported.";
    }
    leaf ima-template {
        type string;
        description
            "Name of the template used for event logs,
            e.g., ima, ima-ng, ima-sig.";
    }
    leaf filename-hint {
        type string;
        description
            "File name (including the path) that was measured.";
    }
    leaf filedata-hash {
        type binary;
        description
            "Hash of filedata as updated based upon the
            filedata-hash-algorithm.";
    }
    leaf filedata-hash-algorithm {
        type string;
        description
            "Algorithm used for filedata-hash.";
    }
    leaf template-hash-algorithm {
        type string;
    }
}
```

```
        description
            "Algorithm used for template-hash.";
    }
    leaf template-hash {
        type binary;
        description
            "hash(filedata-hash, filename-hint)";
    }
    leaf pcr-index {
        type pcr;
        description
            "Defines the PCR index that this event extended.";
    }
    leaf signature {
        type binary;
        description
            "Digital file signature that provides a
            fingerprint for the file being measured.";
    }
}

grouping ima-event-log {
    description
        "Measurement log created by IMA.";
    list ima-event-entry {
        key "event-number";
        description
            "Ordered list of IMA event logs by event-number.";
        uses ima-event;
    }
}

grouping network-equipment-boot-event-log {
    description
        "Measurement log created by Network Equipment Boot. The
        Network Equipment Boot format is identical to the IMA
        format. In contrast to the IMA log, the Network Equipment
        Boot log includes every measurable event from an Attester,
        including the boot stages of BIOS, Bootloader, etc. In
        essence, the scope of events represented in this format
        combines the scope of BIOS events and IMA events.";
    list boot-event-entry {
        key "event-number";
        description
            "Ordered list of Network Equipment Boot event logs
            by event-number, using the IMA event format.";
        uses ima-event;
    }
}

grouping event-logs {
    description
        "A selector for the log and its type.";
    choice attested_event_log_type {
        mandatory true;
        description
            "Event log type determines the event log's content.";
        case bios {
```

```

    if-feature "bios";
    description
      "BIOS/UEFI event logs.";
    container bios-event-logs {
      description
        "BIOS/UEFI event logs.";
      uses bios-event-log;
    }
  }
  case ima {
    if-feature "ima";
    description
      "IMA event logs.";
    container ima-event-logs {
      description
        "IMA event logs.";
      uses ima-event-log;
    }
  }
  case netequip_boot {
    if-feature "netequip_boot";
    description
      "Network Equipment Boot event logs.";
    container boot-event-logs {
      description
        "Network Equipment Boot event logs.";
      uses network-equipment-boot-event-log;
    }
  }
}

/*****/
/*  RPC operations  */
/*****/

rpc tpm12-challenge-response-attestation {
  if-feature "taa:tpm12";
  description
    "This RPC accepts the input for TSS TPM 1.2 commands made to
    the attesting device.";
  input {
    container tpm12-attestation-challenge {
      description
        "This container includes every information element defined
        in the reference challenge-response interaction model for
        remote attestation. Corresponding values are based on
        TPM 1.2 structure definitions";
      uses tpm12-pcr-selection;
      uses nonce;
      leaf-list certificate-name {
        if-feature "tpm:mtpm";
        type certificate-name-ref;
        must "/tpm:rats-support-structures/tpm:tpms"
          + "/tpm:tpm[tpm:firmware-version='taa:tpm12']"
          + "/tpm:certificates/"
          + "/tpm:certificate[name=current()]" {
          error-message "Not an available TPM1.2 AIK certificate.";
        }
      }
    }
  }
}

```

```

    }
    description
      "When populated, the RPC will only get a Quote for the
      TPMs associated with these certificate(s).";
  }
}
}
output {
  list tpm12-attestation-response {
    unique "certificate-name";
    description
      "The binary output of TPM 1.2 TPM_Quote/TPM_Quote2,
      including the PCR selection and other associated
      attestation evidence metadata.";
    uses certificate-name-ref {
      description
        "Certificate associated with this tpm12-attestation.";
    }
    uses tpm12-attestation;
  }
}
}

rpc tpm20-challenge-response-attestation {
  if-feature "taa:tpm20";
  description
    "This RPC accepts the input for TSS TPM 2.0 commands of the
    managed device. ComponentIndex from the hardware manager YANG
    module is used to refer to dedicated TPM in composite devices,
    e.g., smart NICs are not covered.";
  input {
    container tpm20-attestation-challenge {
      description
        "This container includes every information element defined
        in the reference challenge-response interaction model for
        remote attestation. Corresponding values are based on
        TPM 2.0 structure definitions.";
      uses nonce;
      uses tpm20-pcr-selection;
      leaf-list certificate-name {
        if-feature "tpm:mtpm";
        type certificate-name-ref;
        must "/tpm:rats-support-structures/tpm:tpms"
          + "/tpm:tpm[tpm:firmware-version='taa:tpm20']"
          + "/tpm:certificates/"
          + "/tpm:certificate[name=current()]" {
          error-message "Not an available TPM2.0 AIK certificate.";
        }
        description
          "When populated, the RPC will only get a Quote for the
          TPMs associated with the certificates.";
      }
    }
  }
  output {
    list tpm20-attestation-response {
      unique "certificate-name";
      description

```

```

        "The binary output of TPM2_Quote from one TPM of the
        node, which is identified by node-id. A TPMS_ATTEST
        structure including a length, encapsulated in a
        signature.";
    uses certificate-name-ref {
        description
            "Certificate associated with this tpm20-attestation.";
    }
    uses tpm20-attestation;
}
}
}

rpc log-retrieval {
    description
        "Log entries are identified either via indices or by providing
        the last line received. The number of lines returned can be
        limited. The type of log is a choice that can be augmented.";
    input {
        uses log-identifier;
        list log-selector {
            description
                "Only log entries that meet all of the provided selection
                criteria are to be returned by the RPC output.";
            leaf-list name {
                type string;
                description
                    "Name of one or more unique TPMs on a device. If this
                    object exists, a selection should pull only the objects
                    related to these TPM(s). If it does not exist, all
                    qualifying TPMs that are 'hardware-based' equals true
                    on the device are selected. When this selection
                    criteria is provided, it will be considered as a logical
                    AND with any other selection criteria provided.";
            }
            choice index-type {
                description
                    "Last log entry received, log index number, or
                    timestamp.";
                case last-entry {
                    description
                        "The last entry of the log already retrieved.";
                    leaf last-entry-value {
                        type binary;
                        description
                            "Content of a log event that matches 1:1 with a
                            unique event record contained within the log. Log
                            entries after this will be passed to the
                            requester. Note: if log entry values are not
                            unique, this MUST return an error.";
                    }
                }
                case index {
                    description
                        "Numeric index of the last log entry retrieved, or
                        zero.";
                    leaf last-index-number {
                        type uint64;
                    }
                }
            }
        }
    }
}

```

```

        description
            "The last numeric index number of a log entry.
            Zero means to start at the beginning of the log.
            Entries after this will be passed to the
            requester.";
    }
}
case timestamp {
    leaf timestamp {
        type yang:date-and-time;
        description
            "Timestamp from which to start the extraction. The
            next log entry after this timestamp is to
            be sent.";
    }
    description
        "Timestamp from which to start the extraction.";
}
}
leaf log-entry-quantity {
    type uint16;
    description
        "The number of log entries to be returned. If omitted, it
        means all of them.";
}
}
}
output {
    container system-event-logs {
        description
            "The requested data of the measurement event logs.";
        list node-data {
            unique "name";
            description
                "Event logs of a node in a distributed system
                identified by the node name.";
            uses tpm-name;
            uses node-uptime;
            container log-result {
                description
                    "The requested entries of the corresponding log.";
                uses event-logs;
            }
        }
    }
}
}

/*****
/*   Config and Oper accessible nodes   */
*****/

container rats-support-structures {
    description
        "The datastore definition enabling Verifiers or Relying
        Parties to discover the information necessary to use the
        remote attestation RPCs appropriately.";
    container compute-nodes {

```

```

if-feature "tpm:tpm";
description
  "Holds the set of device subsystems/components in this
  composite device that support TPM operations.";
list compute-node {
  key "node-id";
  unique "node-name";
  config false;
  min-elements 2;
  description
    "A component within this composite device that
    supports TPM operations.";
  leaf node-id {
    type string;
    description
      "ID of the compute node, such as Board Serial Number.";
  }
  leaf node-physical-index {
    if-feature "hw:entity-mib";
    type int32 {
      range "1..2147483647";
    }
    config false;
    description
      "The entPhysicalIndex for the compute node.";
    reference
      "RFC 6933: Entity MIB (Version 4) - entPhysicalIndex";
  }
  leaf node-name {
    type string;
    description
      "Name of the compute node.";
  }
  leaf node-location {
    type string;
    description
      "Location of the compute node, such as slot number.";
  }
}
}
}
container tpms {
  description
    "Holds the set of TPMs within an Attester.";
  list tpm {
    key "name";
    unique "path";
    description
      "A list of TPMs in this composite device that RATS
      can be conducted with.";
    uses tpm-name;
    leaf hardware-based {
      type boolean;
      config false;
      mandatory true;
      description
        "System-generated indication of whether this is a
        hardware-based TPM.";
    }
  }
}

```

```
leaf physical-index {
  if-feature "hw:entity-mib";
  type int32 {
    range "1..2147483647";
  }
  config false;
  description
    "The entPhysicalIndex for the TPM.";
  reference
    "RFC 6933: Entity MIB (Version 4) - entPhysicalIndex";
}
leaf path {
  type string;
  config false;
  description
    "Device path to a unique TPM on a device. This can
    change across reboots.";
}
leaf compute-node {
  if-feature "tpm:mtpm";
  type compute-node-ref;
  config false;
  mandatory true;
  description
    "Indicates the compute node measured by this TPM.";
}
leaf manufacturer {
  type string;
  config false;
  description
    "TPM manufacturer name.";
}
leaf firmware-version {
  type identityref {
    base taa:cryptoprocessor;
  }
  mandatory true;
  description
    "Identifies the cryptoprocessor API set supported. This
    is automatically configured by the device and should not
    be changed.";
}
uses tpm12-hash-algo {
  when "derived-from-or-self(firmware-version, 'taa:tpm12')";
  if-feature "taa:tpm12";
  refine "tpm12-hash-algo" {
    description
      "The hash algorithm overwrites the default used for
      PCRs on this TPM1.2-compliant cryptoprocessor.";
  }
}
leaf-list tpm12-pcrs {
  when "derived-from-or-self(..../firmware-version, "
    + "'taa:tpm12')";
  if-feature "taa:tpm12";
  type pcr;
  description
    "The PCRs that may be extracted from this TPM1.2-
```

```

    compliant cryptoprocessor.";
}
list tpm20-pcr-bank {
  when "derived-from-or-self(..../firmware-version, "
    + "'taa:tpm20')";
  if-feature "taa:tpm20";
  key "tpm20-hash-algo";
  description
    "Specifies the list of PCRs that may be extracted for
    a specific hash algorithm on this TPM2-compliant
    cryptoprocessor. A bank is a set of PCRs that are
    extended using a particular hash algorithm.";
  reference
    "TPM2.0-Structures:
    Trusted Platform Module Library Part 2: Structures,
    https://www.trustedcomputinggroup.org/wp-content/
    uploads/TPM-Rev-2.0-Part-2-Structures-01.38.pdf,
    Section 10.9.7";
  leaf tpm20-hash-algo {
    type identityref {
      base taa:hash;
    }
    must '/tpm:rats-support-structures'
      + '/tpm:attester-supported-algos'
      + '/tpm:tpm20-hash' {
      error-message "This platform does not support "
        + "tpm20-hash-algo";
    }
    description
      "The hash scheme actively being used to hash
      one or more TPM2.0 PCRs.";
  }
  leaf-list pcr-index {
    type tpm:pcr;
    description
      "Defines which TPM2.0 PCRs are available to be
      extracted.";
  }
}
leaf status {
  type enumeration {
    enum operational {
      value 0;
      description
        "The TPM currently is running normally and
        is ready to accept and process TPM quotes.";
      reference
        "TPM2.0-Arch:
        Trusted Platform Module Library Part 1:
        Architecture, https://trustedcomputinggroup.org/
        wp-content/uploads/
        TCG_TPM2_r1p59_Part1_Architecture_pub.pdf,
        Section 12";
    }
    enum non-operational {
      value 1;
      description
        "TPM is in a state such as startup or shutdown, which

```

```

        precludes the processing of TPM quotes.";
    }
}
config false;
mandatory true;
description
    "TPM chip self-test status.";
}
container certificates {
    description
        "The TPM's certificates, including EK Certificates
        and Attestation Key Certificates.";
    list certificate {
        key "name";
        description
            "Three types of certificates can be accessed via
            this statement, including Initial Attestation
            Key Certificate, Local Attestation Key Certificate, or
            Endorsement Key Certificate.";
        leaf name {
            type string;
            description
                "An arbitrary name uniquely identifying a certificate
                associated with a key within a TPM.";
        }
        leaf keystore-ref {
            if-feature "ks:central-keystore-supported";
            if-feature "ks:asymmetric-keys";
            type leafref {
                path "/ks:keystore/ks:asymmetric-keys"
                    + "/ks:asymmetric-key/ks:name";
            }
            description
                "A reference to a specific certificate of an
                asymmetric key in the keystore.";
        }
        leaf type {
            type enumeration {
                enum endorsement-certificate {
                    value 0;
                    description
                        "Endorsement Key (EK) Certificate type.";
                    reference
                        "TPM2.0-Key:
                        TPM 2.0 Keys for Device Identity and Attestation
                        https://trustedcomputinggroup.org/wp-content/uploads/TPM-2p0-Keys-for-Device-Identity-and-Attestation\_v1\_r12\_pub10082021.pdf,
                        Section 3.11";
                }
                enum initial-attestation-certificate {
                    value 1;
                    description
                        "Initial Attestation Key (IAK) Certificate
                        type.";
                    reference
                        "TPM2.0-Key:
                        TPM 2.0 Keys for Device Identity and Attestation

```


2.1.2.3. YANG Module

```

<CODE BEGINS> file "ietf-tcg-algs@2024-10-22.yang"

module ietf-tcg-algs {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-tcg-algs";
  prefix taa;

  organization
    "IETF RATS (Remote ATtestation procedureS) Working Group";
  contact
    "WG Web: <https://datatracker.ietf.org/wg/rats/>
    WG List: <mailto:rats@ietf.org>
    Author: Eric Voit <mailto:evoit@cisco.com>";
  description
    "This module defines identities for asymmetric algorithms.

    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.

    Copyright (c) 2024 IETF Trust and the persons identified as
    authors of the code. All rights reserved.

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

    This version of this YANG module is part of RFC 9684; see the
    RFC itself for full legal notices.";

  revision 2024-10-22 {
    description
      "Initial version";
    reference
      "RFC 9684: A YANG Data Model for Challenge-Response-Based
      Remote Attestation (CHARRA) Procedures Using Trusted Platform
      Modules (TPMs)";
  }

  /*****/
  /* Features */
  /*****/

  feature tpm12 {
    description
      "This feature indicates algorithm support for the TPM 1.2 API
      per Section 4.8 of TPM1.2-Structures.";
    reference
      "TPM1.2-Structures: TPM Main Part 2 TPM Structures,
      https://trustedcomputinggroup.org/wp-content/uploads/

```

```
    TPM-Main-Part-2-TPM-Structures_v1.2_rev116_01032011.pdf
    TPM_ALGORITHM_ID values, Section 4.8";
}

feature tpm20 {
  description
    "This feature indicates algorithm support for the TPM 2.0 API
    per Section 11.4 of Trusted Platform Module Library Part 1:
    Architecture.";
  reference
    "TPM2.0-Arch: Trusted Platform Module Library Part 1:
    Architecture, https://trustedcomputinggroup.org/wp-content/
    uploads/TCG\_TPM2\_r1p59\_Part1\_Architecture\_pub.pdf,
    Section 11.4";
}

/*****
/* Identities */
*****/

identity asymmetric {
  description
    "A TCG-recognized asymmetric algorithm with a public and
    private key.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 2,
    https://trustedcomputinggroup.org/resource/
    tcg-algorithm-registry/TCG-\_Algorithm\_Registry\_r1p32\_pub";
}

identity symmetric {
  description
    "A TCG-recognized symmetric algorithm with only a private
    key.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 2";
}

identity hash {
  description
    "A TCG-recognized hash algorithm that compresses input data to
    a digest value or indicates a method that uses a hash.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 2";
}

identity signing {
  description
    "A TCG-recognized signing algorithm";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 2";
}

identity anonymous_signing {
  description
    "A TCG-recognized anonymous signing algorithm.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 2";
}
```

```
}

identity encryption_mode {
  description
    "A TCG-recognized encryption mode.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 2";
}

identity method {
  description
    "A TCG-recognized method such as a mask generation function.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 2";
}

identity object_type {
  description
    "A TCG-recognized object type.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 2";
}

identity cryptoprocessor {
  description
    "Base identity identifying a cryptoprocessor.";
}

identity tpm12 {
  if-feature "tpm12";
  base cryptoprocessor;
  description
    "Supportable by a TPM 1.2.";
  reference
    "TPM1.2-Structures:
    TPM Main Part 2 TPM Structures,
    https://trustedcomputinggroup.org/wp-content/uploads/
    TPM-Main-Part-2-TPM-Structures_v1.2_rev116_01032011.pdf
    TPM_ALGORITHM_ID values, Section 4.8";
}

identity tpm20 {
  if-feature "tpm20";
  base cryptoprocessor;
  description
    "Supportable by a TPM 2.0";
  reference
    "TPM2.0-Structures:
    Trusted Platform Module Library Part 2: Structures,
    https://trustedcomputinggroup.org/wp-content/uploads/
    TPM-Rev-2.0-Part-2-Structures-01.38.pdf";
}

identity TPM_ALG_RSA {
  if-feature "tpm12 or tpm20";
  base tpm12;
  base tpm20;
  base asymmetric;
}
```

```
base object_type;
description
  "RSA algorithm.";
reference
  "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
  RFC 8017. ALG_ID: 0x0001";
}

identity TPM_ALG_TDES {
  if-feature "tpm12";
  base tpm12;
  base symmetric;
  description
    "Block cipher with various key sizes (Triple Data Encryption
    Algorithm, commonly called Triple Data Encryption Standard)
    Note: Was banned in TPM 1.2, v94";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 18033-3. ALG_ID: 0x0003";
}

identity TPM_ALG_SHA1 {
  if-feature "tpm12 or tpm20";
  base hash;
  base tpm12;
  base tpm20;
  description
    "SHA1 algorithm - Deprecated due to insufficient cryptographic
    protection. However, it is still useful for hash algorithms
    where protection is not required.";
  reference
    "TCG-Algos: TCG Algorithm Registry Rev1.32, Table 3, and
    ISO/IEC 10118-3. ALG_ID: 0x0004";
}

identity TPM_ALG_HMAC {
  if-feature "tpm12 or tpm20";
  base tpm12;
  base tpm20;
  base hash;
  base signing;
  description
    "Hash Message Authentication Code (HMAC) algorithm.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 9797-2, and
    RFC 2104. ALG_ID: 0x0005";
}

identity TPM_ALG_AES {
  if-feature "tpm12";
  base tpm12;
  base symmetric;
  description
    "The AES algorithm with various key sizes.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 18033-3. ALG_ID: 0x0006";
}
```

```
}

identity TPM_ALG_MGF1 {
  if-feature "tpm20";
  base tpm20;
  base hash;
  base method;
  description
    "Hash-based mask-generation function.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    IEEE Std 1363-2000, and
    IEEE Std 1363a-2004.
    ALG_ID: 0x0007";
}

identity TPM_ALG_KEYEDHASH {
  if-feature "tpm20";
  base tpm20;
  base hash;
  base object_type;
  description
    "An encryption or signing algorithm using a keyed hash. These
    may use XOR for encryption or an HMAC for signing and may
    also refer to a data object that is neither signing nor
    encrypting.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3.
    ALG_ID: 0x0008";
}

identity TPM_ALG_XOR {
  if-feature "tpm12 or tpm20";
  base tpm12;
  base tpm20;
  base hash;
  base symmetric;
  description
    "The XOR encryption algorithm.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3.
    ALG_ID: 0x000A";
}

identity TPM_ALG_SHA256 {
  if-feature "tpm20";
  base tpm20;
  base hash;
  description
    "The SHA-256 algorithm.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 10118-3. ALG_ID: 0x000B";
}

identity TPM_ALG_SHA384 {
  if-feature "tpm20";
  base tpm20;
```

```
base hash;
description
  "The SHA-384 algorithm.";
reference
  "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
  ISO/IEC 10118-3. ALG_ID: 0x000C";
}

identity TPM_ALG_SHA512 {
  if-feature "tpm20";
  base tpm20;
  base hash;
  description
    "The SHA-512 algorithm.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 10118-3. ALG_ID: 0x000D";
}

identity TPM_ALG_NULL {
  if-feature "tpm20";
  base tpm20;
  description
    "Null algorithm.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3.
    ALG_ID: 0x0010";
}

identity TPM_ALG_SM3_256 {
  if-feature "tpm20";
  base tpm20;
  base hash;
  description
    "The ShangMi 3 (SM3) hash algorithm.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 10118-3:2018. ALG_ID: 0x0012";
}

identity TPM_ALG_SM4 {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  description
    "ShangMi 4 (SM4) symmetric block cipher.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3.
    ALG_ID: 0x0013";
}

identity TPM_ALG_RSASSA {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base signing;
  description
    "Signature algorithm defined in Section 8.2
```

```
(RSASSA-PKCS1-v1_5) of RFC 8017.";
reference
  "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
  RFC 8017. ALG_ID: 0x0014";
}

identity TPM_ALG_RSAES {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base encryption_mode;
  description
    "Signature algorithm defined in Section 7.2
    (RSAES-PKCS1-v1_5) of RFC 8017.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    RFC 8017. ALG_ID: 0x0015";
}

identity TPM_ALG_RSAPSS {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base signing;
  description
    "Padding algorithm defined in Section 8.1 (RSASSA-PSS)
    of RFC 8017.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    RFC 8017. ALG_ID: 0x0016";
}

identity TPM_ALG_OAEP {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base encryption_mode;
  description
    "Padding algorithm defined in Section 7.1 (RSAES-OAEP)
    of RFC 8017.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    RFC 8017. ALG_ID: 0x0017";
}

identity TPM_ALG_ECDSA {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base signing;
  description
    "Signature algorithm using elliptic curve cryptography (ECC).";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 14888-3. ALG_ID: 0x0018";
}

identity TPM_ALG_ECDH {
```

```
if-feature "tpm20";
base tpm20;
base asymmetric;
base method;
description
  "Secret sharing using ECC.";
reference
  "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
  NIST SP800-56A. ALG_ID: 0x0019";
}

identity TPM_ALG_ECDSA {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base signing;
  base anonymous_signing;
  description
    "Elliptic-curve-based, anonymous signing scheme.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    TCG TPM 2.0 Library. ALG_ID: 0x001A";
}

identity TPM_ALG_SM2 {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base signing;
  base encryption_mode;
  base method;
  description
    "SM2 - depending on context, either an elliptic-curve based,
    signature algorithm, an encryption scheme, or a key exchange
    protocol.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3.
    ALG_ID: 0x001B";
}

identity TPM_ALG_EC Schnorr {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base signing;
  description
    "Elliptic-curve-based Schnorr signature.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3.
    ALG_ID: 0x001C";
}

identity TPM_ALG_ECMQV {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base method;
  description
```

```
    "Two-phase elliptic-curve key.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    NIST SP800-56A. ALG_ID: 0x001D";
}

identity TPM_ALG_KDF1_SP800_56A {
  if-feature "tpm20";
  base tpm20;
  base hash;
  base method;
  description
    "Concatenation key derivation function.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    NIST SP800-56A (approved alternative1) Section 5.8.1.
    ALG_ID: 0x0020";
}

identity TPM_ALG_KDF2 {
  if-feature "tpm20";
  base tpm20;
  base hash;
  base method;
  description
    "Key derivation function.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    IEEE 1363a-2004, KDF2, Section 13.2. ALG_ID: 0x0021";
}

identity TPM_ALG_KDF1_SP800_108 {
  base TPM_ALG_KDF2;
  description
    "A key derivation method.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3 and
    NIST SP800-108, Section 5.1, KDF. ALG_ID: 0x0022";
}

identity TPM_ALG_ECC {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base object_type;
  description
    "Prime field ECC.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 15946-1. ALG_ID: 0x0023";
}

identity TPM_ALG_SYMCIPHER {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base object_type;
  description
```

```
    "Object type for a symmetric block cipher.";
    reference
      "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
       TCG TPM 2.0 Library. ALG_ID: 0x0025";
  }

  identity TPM_ALG_CAMELLIA {
    if-feature "tpm20";
    base tpm20;
    base symmetric;
    description
      "The Camellia algorithm.";
    reference
      "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
       ISO/IEC 18033-3. ALG_ID: 0x0026";
  }

  identity TPM_ALG_SHA3_256 {
    if-feature "tpm20";
    base tpm20;
    base hash;
    description
      "ISO/IEC 10118-3 - the SHA-256 algorithm.";
    reference
      "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
       NIST FIPS 202. ALG_ID: 0x0027";
  }

  identity TPM_ALG_SHA3_384 {
    if-feature "tpm20";
    base tpm20;
    base hash;
    description
      "The SHA-384 algorithm.";
    reference
      "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
       NIST FIPS 202. ALG_ID: 0x0028";
  }

  identity TPM_ALG_SHA3_512 {
    if-feature "tpm20";
    base tpm20;
    base hash;
    description
      "The SHA-512 algorithm.";
    reference
      "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
       NIST FIPS 202. ALG_ID: 0x0029";
  }

  identity TPM_ALG_CMAC {
    if-feature "tpm20";
    base tpm20;
    base symmetric;
    base signing;
    description
      "Block Cipher-based Message Authentication Code (CMAC).";
    reference
```

```
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 9797-1:2011, Algorithm 5. ALG_ID: 0x003F";
}

identity TPM_ALG_CTR {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base encryption_mode;
  description
    "Counter mode.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 10116. ALG_ID: 0x0040";
}

identity TPM_ALG_OFB {
  base tpm20;
  base symmetric;
  base encryption_mode;
  description
    "Output Feedback mode.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 10116. ALG_ID: 0x0041";
}

identity TPM_ALG_CBC {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base encryption_mode;
  description
    "Cipher Block Chaining mode.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 10116. ALG_ID: 0x0042";
}

identity TPM_ALG_CFB {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base encryption_mode;
  description
    "Cipher Feedback mode.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    ISO/IEC 10116. ALG_ID: 0x0043";
}

identity TPM_ALG_ECB {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base encryption_mode;
  description
    "Electronic Codebook mode.";
```

```
reference
  "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
  ISO/IEC 10116. ALG_ID: 0x0044";
}

identity TPM_ALG_CCM {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base signing;
  base encryption_mode;
  description
    "Counter with Cipher Block Chaining--Message Authentication
    Code (CCM).";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    NIST SP800-38C. ALG_ID: 0x0050";
}

identity TPM_ALG_GCM {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base signing;
  base encryption_mode;
  description
    "Galois/Counter Mode (GCM).";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    NIST SP800-38D. ALG_ID: 0x0051";
}

identity TPM_ALG_KW {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base signing;
  base encryption_mode;
  description
    "AES Key Wrap (KW).";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    NIST SP800-38F. ALG_ID: 0x0052";
}

identity TPM_ALG_KWP {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base signing;
  base encryption_mode;
  description
    "AES Key Wrap with Padding (KWP).";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    NIST SP800-38F. ALG_ID: 0x0053";
}
```

```
identity TPM_ALG_EAX {
  if-feature "tpm20";
  base tpm20;
  base symmetric;
  base signing;
  base encryption_mode;
  description
    "Authenticated-Encryption Mode.";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    NIST SP800-38F. ALG_ID: 0x0054";
}

identity TPM_ALG_EDDSA {
  if-feature "tpm20";
  base tpm20;
  base asymmetric;
  base signing;
  description
    "Edwards-curve Digital Signature Algorithm (PureEdDSA).";
  reference
    "TCG-Algos: TCG Algorithm Registry, Rev1.32, Table 3, and
    RFC 8032. ALG_ID: 0x0060";
}
}

<CODE ENDS>
```

Note that not all cryptographic functions are required for use by `ietf-tpm-remote-attestation.yang`. However, the full definition of Table 3 of [TCG-Algos] will allow use by additional YANG specifications.

3. IANA Considerations

This document registers the following namespace URIs in the [XML-Registry] per [RFC3688]:

URI: `urn:ietf:params:xml:ns:yang:ietf-tpm-remote-attestation`

Registrant Contact: The IESG.

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

URI: `urn:ietf:params:xml:ns:yang:ietf-tcg-algs`

Registrant Contact: The IESG.

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

This document registers the following YANG modules in the registry [YANG-Parameters] per Section 14 of [RFC6020]:

Name: ietf-tpm-remote-attestation

Namespace: urn:ietf:params:xml:ns:yang:ietf-tpm-remote-attestation

Prefix: tpm

Reference: draft-ietf-rats-yang-tpm-charra (RFC form)

Name: ietf-tcg-algs

Namespace: urn:ietf:params:xml:ns:yang:ietf-tcg-algs

Prefix: taa

Reference: draft-ietf-rats-yang-tpm-charra (RFC form)

4. Security Considerations

The YANG module `ietf-tpm-remote-attestation.yang` 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 as well as their sensitivity/vulnerability:

Container `/rats-support-structures/attester-supported-algos`: `'tpm12-asymmetric-signing'`, `'tpm12-hash'`, `'tpm20-asymmetric-signing'`, and `'tpm20-hash'`. All could be populated with algorithms that are not supported by the underlying physical TPM installed by the equipment vendor. A vendor should restrict the ability to configure unsupported algorithms.

Container: `/rats-support-structures/tpms`: `'name'`: Although shown as `'rw'`, it is system generated. Therefore, it should not be possible for an operator to add or remove a TPM from the configuration.

`'tpm20-pcr-bank'`: It is possible to configure PCRs that are not being extended by system software for extraction. This could unnecessarily use TPM resources.

'certificates': It is possible to provision a certificate that does not correspond to an AIK within the TPM 1.2, or to an Attestation Key (AK) within the TPM 2.0, respectively. In such a case, calls to an RPC requesting this specific certificate could result in either no response or a response from an unexpected TPM.

RPC 'tpm12-challenge-response-attestation': The receiver of the RPC response must verify that the certificate is for an active AIK, i.e., the certificate has been confirmed by a third party as being able to support Attestation on the targeted TPM 1.2.

RPC 'tpm20-challenge-response-attestation': The receiver of the RPC response must verify that the certificate is for an active AK, i.e., the private key confirmation of the quote signature within the RPC response has been confirmed by a third party to belong to an entity legitimately able to perform Attestation on the targeted TPM 2.0.

RPC 'log-retrieval': Requesting a large volume of logs from the Attester could require significant system resources and create a denial of service.

Information collected through the RPCs above could reveal specific versions of software and configurations of endpoints that could identify vulnerabilities on those systems. Therefore, RPCs should be protected by NACM [RFC8341] with a default setting of deny-all to limit the extraction of attestation data by only authorized Verifiers.

For the YANG module `ietf-tcg-algs.yang`, please use care when selecting specific algorithms. The introductory section of [TCG-Algos] highlights that some algorithms should be considered legacy, and recommends implementers and adopters diligently evaluate available information such as governmental, industrial, and academic research before selecting an algorithm for use.

5. References

5.1. Normative References

[BIOS-Log] Trusted Computing Group, "TCG PC Client Platform Firmware Profile Specification", Family "2.0" Level 00 Revision 1.03 Version 51, 1 May 2017, <https://trustedcomputinggroup.org/wp-content/uploads/PC-ClientSpecific_Platform_Profile_for_TPM_2p0_Systems_v51.pdf>.

[BIOS-Log-Event-Type] Trusted Computing Group, "TCG PC Client Platform Firmware Profile Specification", Family "2.0" Level 00 Version 1.05 Revision 23, 7 May 2017, <https://trustedcomputinggroup.org/wp-content/uploads/TCG_PCClient_PFP_r1p05_v23_pub.pdf>.

[CEL] Trusted Computing Group, "Canonical Event Log Format", Version 1.0 Revision 0.41, 25 February 2022, <https://trustedcomputinggroup.org/wp-content/uploads/TCG_IWG_CEL_v1_r0p41_pub.pdf>.

[IEEE-Std-1363-2000] IEEE, "IEEE Standard Specifications for Public-Key Cryptography", IEEE Std 1363-2000, DOI 10.1109/IEEESTD.2000.92292, August 2000, <<https://ieeexplore.ieee.org/document/891000>>.

-
- [IEEE-Std-1363a-2004]** IEEE, "IEEE Standard Specifications for Public-Key Cryptography - Amendment 1: Additional Techniques", IEEE Std 1363a-2004, DOI 10.1109/IEEESTD.2004.94612, September 2004, <<https://ieeexplore.ieee.org/document/1335427>>.
- [ISO-IEC-10116]** ISO/IEC, "Information technology - Security techniques - Modes of operation for an n-bit block cipher", Edition 4, ISO/IEC 10116:2017, July 2017, <<https://www.iso.org/standard/64575.html>>.
- [ISO-IEC-10118-3]** ISO/IEC, "IT Security techniques - Hash-functions - Part 3: Dedicated hash-functions", Edition 4, ISO/IEC 10118-3:2018, October 2018, <<https://www.iso.org/standard/67116.html>>.
- [ISO-IEC-14888-3]** ISO/IEC, "Security techniques - Digital signatures with appendix - Part 3: Discrete logarithm based mechanisms", Edition 4, ISO/IEC 14888-3:2018, November 2018, <<https://www.iso.org/standard/76382.html>>.
- [ISO-IEC-15946-1]** ISO/IEC, "Information technology - Security techniques - Cryptographic techniques based on elliptic curves - Part 1: General", Edition 3, ISO/IEC 15946-1:2016, July 2016, <<https://www.iso.org/standard/65480.html>>.
- [ISO-IEC-18033-3]** ISO/IEC, "Information technology - Security techniques - Encryption algorithms - Part 3: Block ciphers", Edition 2, ISO/IEC 18033-3:2010, December 2010, <<https://www.iso.org/standard/54531.html>>.
- [ISO-IEC-9797-1]** ISO/IEC, "Information technology - Security techniques - Message Authentication Codes (MACs) - Part 1: Mechanisms using a block cipher", Edition 2, ISO/IEC 9797-1:2011, November 2011, <<https://www.iso.org/standard/50375.html>>.
- [ISO-IEC-9797-2]** ISO/IEC, "Information technology - Security techniques - Message authentication codes (MACs) - Part 2: Mechanisms using a dedicated hash-function", Edition 2, ISO/IEC 9797-2:2011, November 2011, <<https://www.iso.org/standard/51618.html>>.
- [NIST-FIPS-202]** NIST, "SHA-3 Standard: Permutation-Based Hash and Extendable-Output Functions", NIST FIPS 202, DOI 10.6028/NIST.FIPS.202, August 2015, <<https://csrc.nist.gov/publications/detail/fips/202/final>>.
- [NIST-SP800-108]** Chen, L., "Recommendation for Key Derivation Using Pseudorandom Functions (Revised)", NIST SP 800-108, DOI 10.6028/NIST.SP.800-108, 1 October 2009, <<https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-108.pdf>>.
- [NIST-SP800-38C]** Dworkin, M., "Recommendation for Block Cipher Modes of Operation: the CCM Mode for Authentication and Confidentiality", NIST SP 800-38C, DOI 10.6028/NIST.SP.800-38C, July 2007, <<https://csrc.nist.gov/publications/detail/sp/800-38c/final>>.

-
- [NIST-SP800-38D] Dworkin, M., "Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC", NIST SP 800-38D, DOI 10.6028/NIST.SP.800-38D, November 2007, <<https://csrc.nist.gov/publications/detail/sp/800-38d/final>>.
- [NIST-SP800-38F] Dworkin, M., "Recommendation for Block Cipher Modes of Operation: Methods for Key Wrapping", NIST SP 800-38F, DOI 10.6028/NIST.SP.800-38F, December 2012, <<https://csrc.nist.gov/publications/detail/sp/800-38f/final>>.
- [NIST-SP800-56A] Barker, E., Chen, L., Roginsky, A., Vassilev, A., and R. Davis, "Recommendation for Pair-Wise Key-Establishment Schemes Using Discrete Logarithm Cryptography", NIST SP 800-56A Rev. 3, DOI 10.6028/NIST.SP.800-56Ar3, April 2018, <<https://csrc.nist.gov/publications/detail/sp/800-56a/rev-3/final>>.
- [RFC2104] Krawczyk, H., Bellare, M., and R. Canetti, "HMAC: Keyed-Hashing for Message Authentication", RFC 2104, DOI 10.17487/RFC2104, February 1997, <<https://www.rfc-editor.org/info/rfc2104>>.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC3688] Mealling, M., "The IETF XML Registry", BCP 81, RFC 3688, DOI 10.17487/RFC3688, January 2004, <<https://www.rfc-editor.org/info/rfc3688>>.
- [RFC6020] Bjorklund, M., Ed., "YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)", RFC 6020, DOI 10.17487/RFC6020, October 2010, <<https://www.rfc-editor.org/info/rfc6020>>.
- [RFC6241] Enns, R., Ed., Bjorklund, M., Ed., Schoenwaelder, J., Ed., and A. Bierman, Ed., "Network Configuration Protocol (NETCONF)", RFC 6241, DOI 10.17487/RFC6241, June 2011, <<https://www.rfc-editor.org/info/rfc6241>>.
- [RFC6242] Wasserman, M., "Using the NETCONF Protocol over Secure Shell (SSH)", RFC 6242, DOI 10.17487/RFC6242, June 2011, <<https://www.rfc-editor.org/info/rfc6242>>.
- [RFC6933] Bierman, A., Romascanu, D., Quittek, J., and M. Chandramouli, "Entity MIB (Version 4)", RFC 6933, DOI 10.17487/RFC6933, May 2013, <<https://www.rfc-editor.org/info/rfc6933>>.
- [RFC6991] Schoenwaelder, J., Ed., "Common YANG Data Types", RFC 6991, DOI 10.17487/RFC6991, July 2013, <<https://www.rfc-editor.org/info/rfc6991>>.
- [RFC8017] Moriarty, K., Ed., Kaliski, B., Jonsson, J., and A. Rusch, "PKCS #1: RSA Cryptography Specifications Version 2.2", RFC 8017, DOI 10.17487/RFC8017, November 2016, <<https://www.rfc-editor.org/info/rfc8017>>.
- [RFC8032] Josefsson, S. and I. Liusvaara, "Edwards-Curve Digital Signature Algorithm (EdDSA)", RFC 8032, DOI 10.17487/RFC8032, January 2017, <<https://www.rfc-editor.org/info/rfc8032>>.

-
- [RFC8040]** Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", RFC 8040, DOI 10.17487/RFC8040, January 2017, <<https://www.rfc-editor.org/info/rfc8040>>.
- [RFC8174]** Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.
- [RFC8341]** Bierman, A. and M. Bjorklund, "Network Configuration Access Control Model", STD 91, RFC 8341, DOI 10.17487/RFC8341, March 2018, <<https://www.rfc-editor.org/info/rfc8341>>.
- [RFC8348]** Bierman, A., Bjorklund, M., Dong, J., and D. Romascanu, "A YANG Data Model for Hardware Management", RFC 8348, DOI 10.17487/RFC8348, March 2018, <<https://www.rfc-editor.org/info/rfc8348>>.
- [RFC8446]** Rescorla, E., "The Transport Layer Security (TLS) Protocol Version 1.3", RFC 8446, DOI 10.17487/RFC8446, August 2018, <<https://www.rfc-editor.org/info/rfc8446>>.
- [RFC9334]** Birkholz, H., Thaler, D., Richardson, M., Smith, N., and W. Pan, "Remote Attestation procedureS (RATS) Architecture", RFC 9334, DOI 10.17487/RFC9334, January 2023, <<https://www.rfc-editor.org/info/rfc9334>>.
- [RFC9642]** Watsen, K., "A YANG Data Model for a Keystore", RFC 9642, DOI 10.17487/RFC9642, October 2024, <<https://www.rfc-editor.org/info/rfc9642>>.
- [RFC9683]** Fedorkow, G., Voit, E., and J. Fitzgerald-McKay, "TPM-based Network Device Remote Integrity Verification", RFC 9683, DOI 10.17487/RFC9683, October 2024, <<https://www.rfc-editor.org/info/rfc9683>>.
- [TCG-Algos]** Trusted Computing Group, "TCG Algorithm Registry", Family "2.0" Level 00 Revision 01.32, 25 June 2020, <https://trustedcomputinggroup.org/wp-content/uploads/TCG_Algorithm_Registry_r1p32_pub.pdf>.
- [TPM1.2]** Trusted Computing Group, "TPM 1.2 Main Specification", TPM Main Specification Level 2 Version 1.2, Revision 116, 1 March 2011, <<https://trustedcomputinggroup.org/resource/tpm-main-specification/>>.
- [TPM1.2-Commands]** Trusted Computing Group, "TPM Main Part 3 Commands", TPM Main Specification Level 2 Version 1.2, Revision 116, 1 March 2011, <https://trustedcomputinggroup.org/wp-content/uploads/TPM-Main-Part-3-Commands_v1.2_rev116_01032011.pdf>.
- [TPM1.2-Structures]** Trusted Computing Group, "TPM Main Part 2 TPM Structures", TPM Main Specification Level 2 Version 1.2, Revision 116, 1 March 2011, <https://trustedcomputinggroup.org/wp-content/uploads/TPM-Main-Part-2-TPM-Structures_v1.2_rev116_01032011.pdf>.
- [TPM2.0]** Trusted Computing Group, "TPM 2.0 Library", Trusted Platform Module Library Specification, Family "2.0", Level 00, Revision 01.83, March 2024, <<https://trustedcomputinggroup.org/resource/tpm-library-specification/>>.
-

- [TPM2.0-Arch]** Trusted Computing Group, "Trusted Platform Module Library Part 1: Architecture", Family "2.0", Level 00, Revision 01.59, 8 November 2019, <https://trustedcomputinggroup.org/wp-content/uploads/TCG_TPM2_r1p59_Part1_Architecture_pub.pdf>.
- [TPM2.0-Key]** Trusted Computing Group, "TPM 2.0 Keys for Device Identity and Attestation", Version 1.00, Revision 12, 8 October 2021, <https://trustedcomputinggroup.org/wp-content/uploads/TPM-2p0-Keys-for-Device-Identity-and-Attestation_v1_r12_pub10082021.pdf>.
- [TPM2.0-Structures]** Trusted Computing Group, "Trusted Platform Module Library Part 2: Structures", Family "2.0", Level 00, Revision 01.38, 29 December 2016, <<https://trustedcomputinggroup.org/wp-content/uploads/TPM-Rev-2.0-Part-2-Structures-01.38.pdf>>.
- [UEFI-Secure-Boot]** Unified Extensible Firmware Interface (UEFI) Forum, Inc., "Unified Extensible Firmware Interface (UEFI) Specification", Section 32.1: Secure Boot, Version 2.9, March 2021, <https://uefi.org/sites/default/files/resources/UEFI_Spec_2_9_2021_03_18.pdf>.

5.2. Informative References

- [IMA-Kernel-Source]** "Linux Integrity Measurement Architecture (IMA): Kernel Sourcecode", commit df0cc57, 9 October 2021, <<https://github.com/torvalds/linux/blob/df0cc57e057f18e44dac8e6c18aba47ab53202f9/security/integrity/ima/>>.
- [NIST-915121]** NIST, "True Randomness Can't be Left to Chance: Why entropy is important for information security", <https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=915121>.
- [RATS-Interaction-Models]** Birkholz, H., Eckel, M., Pan, W., and E. Voit, "Reference Interaction Models for Remote Attestation Procedures", Work in Progress, Internet-Draft, draft-ietf-rats-reference-interaction-models-11, 22 July 2024, <<https://datatracker.ietf.org/doc/html/draft-ietf-rats-reference-interaction-models-11>>.
- [XML-Registry]** IANA, "IETF XML Registry", <<https://www.iana.org/assignments/xml-registry/>>.
- [YANG-Parameters]** IANA, "YANG Parameters", <<https://www.iana.org/assignments/yang-parameters/>>.

Appendix A. Integrity Measurement Architecture (IMA)

IMA extends the principles of Measured Boot [\[TPM2.0-Arch\]](#) and Secure Boot [\[UEFI-Secure-Boot\]](#) to the Linux operating system, applying it to operating system applications and files. IMA has been part of the Linux integrity subsystem of the Linux kernel since 2009 (kernel version 2.6.30). The IMA mechanism represented by the YANG module in this specification is rooted in the kernel version 5.16 [\[IMA-Kernel-Source\]](#). IMA enables the protection of system integrity by collecting (commonly referred to as measuring) and storing measurements (called Claims in the context of

IETF RATS) of files before execution so that these measurements can be used later, at system runtime, in remote attestation procedures. IMA acts in support of the Appraisal of Evidence (which includes measurement Claims) by leveraging Reference Values stored in extended file attributes.

In support of the Appraisal of Evidence, IMA maintains an ordered list (with no duplicates) of measurements in kernel space, the Stored Measurement Log (SML), for all files that have been measured before execution since the operating system was started. Although IMA can be used without a TPM, it is typically used in conjunction with a TPM to anchor the integrity of the SML in a hardware-protected secure storage location, i.e., PCRs provided by TPMs. IMA provides the SML in both binary and ASCII representations in the Linux security file system *securityfs* (`/sys/kernel/security/ima/`).

IMA templates define the format of the SML, i.e., which fields are included in a log record. Examples are file path, file hash, user ID, group ID, file signature, and extended file attributes. IMA comes with a set of predefined template formats and also allows a custom format, i.e., a format consisting of template fields supported by IMA. Template usage is typically determined by boot arguments passed to the kernel. Alternatively, the format can also be hard-coded into custom kernels. IMA templates and fields are extensible in the kernel source code. As a result, more template fields can be added in the future.

IMA policies define which files are measured using the IMA policy language. Built-in policies can be passed as boot arguments to the kernel. Custom IMA policies can be defined once during runtime or be hard-coded into a custom kernel. If no policy is defined, no measurements are taken and IMA is effectively disabled.

A comprehensive description of the content fields in native Linux IMA TLV format can be found in Table 16 of the Canonical Event Log (CEL) specification [CEL]. The CEL specification also illustrates the use of templates to enable extended or customized IMA TLV formats in Section 5.1.6.

Appendix B. IMA for Network Equipment Boot Logs

Network equipment can generally implement similar IMA-protected functions to generate measurements (Claims) about the boot process of a device and enable corresponding remote attestation. Network Equipment Boot Logs combine the measurement and logging of boot components and operating system components (executables and files) into a single log file in a format identical to the IMA format. Note that the format used for logging measurement of boot components in this scheme differs from the boot logging strategy described elsewhere in this document.

During the boot process of the network device, i.e., from BIOS to the end of the operating system and user-space, all files executed can be measured and logged in the order of their execution. When the Verifier initiates a remote attestation process (e.g., challenge-response remote attestation as defined in this document), the network equipment takes on the role of an Attester and can convey to the Verifier Claims that comprise the measurement log as well as the corresponding PCR values (Evidence) of a TPM.

The Verifier can appraise the integrity (compliance with the Reference Values) of each executed file by comparing its measured value with the Reference Value. Based on the execution order, the Verifier can compute a PCR Reference Value (by replaying the log) and compare it to the measurement log Claims obtained in conjunction with the PCR Evidence to assess their trustworthiness with respect to an intended operational state.

Network equipment usually executes multiple components in parallel. This holds not only during the operating system loading phase, but also even during the BIOS boot phase. With this measurement log mechanism, network equipment can assume the role of an Attester, proving to the Verifier the trustworthiness of its boot process. Using the measurement log, Verifiers can precisely identify mismatching log entries to infer potentially tampered components.

This mechanism also supports scenarios that modify files on the Attester that are subsequently executed during the boot phase (e.g., updating/patching) by simply updating the appropriate Reference Values in Reference Integrity Manifests that inform Verifiers about how an Attester is composed.

Authors' Addresses

Henk Birkholz

Fraunhofer SIT
Rheinstrasse 75
64295 Darmstadt
Germany
Email: henk.birkholz@ietf.contact

Michael Eckel

Fraunhofer SIT
Rheinstrasse 75
64295 Darmstadt
Germany
Email: michael.eckel@sit.fraunhofer.de

Shwetha Bhandari

ThoughtSpot
Email: shwetha.bhandari@thoughtspot.com

Eric Voit

Cisco Systems
Email: evoit@cisco.com

Bill Sulzen

Cisco Systems
Email: bsulzen@cisco.com

Liang Xia (Frank)

Huawei Technologies

Yuhuatai District

101 Software Avenue

Nanjing

Jiangsu, 210012

China

Email: Frank.Xialiang@huawei.com**Tom Laffey**

Hewlett Packard Enterprise

Email: tom.laffey@hpe.com**Guy C. Fedorkow**

Juniper Networks

10 Technology Park Drive

Westford, Massachusetts 01886

United States of America

Email: gfedorkow@juniper.net