Network Working Group
Internet-Draft
Intended status: Informational
Expires: September 13, 2019

A. Fuchs
H. Birkholz
Fraunhofer SIT
I. McDonald
High North Inc
C. Bormann
Universitaet Bremen TZI
March 12, 2019

Time-Based Uni-Directional Attestation
draft-birkholz-rats-tuda-00

Abstract

This memo documents the method and bindings used to conduct time-based uni-directional attestation between distinguishable endpoints over the network.

Status of This Memo

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

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

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

This Internet-Draft will expire on September 13, 2019.

Table of Contents

1. Introduction

Remote attestation (RA) describes the attempt to determine and appraise properties, such as integrity and trustworthiness, of an endpoint -- the Attestor -- over a network to another endpoint -- the Verifier -- without direct access. Typically, this kind of appraisal is based on integrity measurements of software components right before they are loaded as software instances on the Attestor. In general, attestation procedures are utilizing a hardware root of trust (RoT). The TUDA protocol family uses hash values of all started software components that are stored (extended into) a Trust-Anchor (the RoT) implemented as a Hardware Security Module (e.g. a Trusted Platform Module or similar) and are reported via a signature over those measurements.

This draft introduces the concept of including the exchange of evidence -- created via a hardware RoT containing a shielded secret that is inaccessible to the user -- in order to increase the confidence in a communication peer that is supposed to be a Trusted System [RFC4949]. In consequence, this document introduces the term forward authenticity.

Forward Authenticity (FA): A property of secure communication protocols, in which later compromise of the long-term keys of a data origin does not compromise past authentication of data from that origin. FA is achieved by timely recording of assessments of the authenticity from entities (via "audit logs" during "audit sessions") that are authorized for this purpose, in a time frame much shorter than that expected for the compromise of the long-term keys.

Forward Authenticity enables new level of guarantee and can be included in the basically every protocol, such as ssh, router advertisements, link layer neighbor discover, or even ICMP echo.

1.1. Remote Attestation

In essence, remote attestation (RA) is composed of three activities. The following definitions are derived from the definitions presented in [PRIRA] and [TCGGLOSS].

Attestation: The creation of one ore more claims about the properties of an Attestor, such that the claims can be used as evidence.

Conveyance: The transfer of evidence from the Attestor to the Verifier via an interconnect.

Verification: The appraisal of evidence by evaluating it against declarative guidance.

With TUDA, the claims that compose the evidence are signatures over trustworthy integrity measurements created by leveraging a hardware RoT. The evidence is appraised via corresponding signatures over reference integrity measurements (RIM, represented, for example via [I-D.ietf-sacm-coswid]).

Protocols that facilitate Trust-Anchor based signatures in order to provide RATS are usually bi-directional challenge/response protocols, such as the Platform Trust Service protocol [PTS] or CAVES [PRIRA], where one entity sends a challenge that is included inside the response to prove the recentness -- the freshness (see fresh in [RFC4949]) -- of the attestation information. The corresponding interaction model tightly couples the three activities of creating, transferring and appraising evidence.

The Time-Based Uni-directional Attestation family of protocols -- TUDA -- described in this document can decouple the three activities RATS are composed of. As a result, TUDA provides additional capabilities, such as:

- remote attestation for Attestors that might not always be able to reach the Internet by enabling the verification of past states,

- secure audit logs by combining the evidence created via TUDA with integrity measurement logs that represent a detailed record of corresponding past states,

- an uni-directional interaction model that can traverse "diode-like" network security functions (NSF) or can be leveraged in RESTful architectures (e.g. CoAP [RFC7252]), analogously.

1.2. Evidence Creation

TUDA is a family of protocols that bundles results from specific attestation activities. The attestation activities of TUDA are based on a hardware Root of Trust that provides the following capabilities:

- Platform Configuration Registers (PCR) that store measurements consecutively (corresponding terminology: "to extend a PCR") and represent the chain of measurements as a single measurement value ("PCR value"),

- Restricted Signing Keys (RSK) that can only be accessed, if a specific signature about measurements can be provided as authentication, and

- a dedicated source of (relative) time, e.g. a tick counter.

1.3. Evidence Appraisal

To appraise the evidence created by an Attestor, the Verifier requires corresponding Reference Integrity Measurements (RIM). Typically, a set of RIM are bundled in a RIM-Manifest (RIMM). The scope of a manifest encompasses, e.g., a platform, a device, a computing context, or a virtualised function. In order to be comparable, the hashing algorithms used by the Attestor to create the integrity measurements have to match the hashing algorithms used to create the corresponding RIM that are used by the Verifier to appraise the integrity evidence.

1.4. Activities and Actions

Depending on the platform (i.e. one or more computing contexts including a dedicated hardware RoT), a generic RA activity results in platform-specific actions that have to be conducted. In consequence, there are multiple specific operations and data models (defining the input and output of operations). Hence, specific actions are are not covered by this document. Instead, the requirements on operations and the information elements that are the input and output to these operations are illustrated using pseudo code in Appendix C and D.

1.5. Attestation and Verification

Both the attestation and the verification activity of TUDA also require a trusted Time Stamp Authority (TSA) as an additional third party next to the Attestor and the Verifier. The protocol uses a Time Stamp Authority based on [RFC3161]. The combination of the local source of time provided by the hardware RoT (located on the Attestor) and the Time Stamp Tokens provided by the TSA (to both the Attestor and the Verifier) enable the attestation and verification of an appropriate freshness of the evidence conveyed by the Attestor -- without requiring a challenge/response interaction model that uses a nonce to ensure the freshness.

Typically, the verification activity requires declarative guidance (representing desired or compliant endpoint characteristics in the form of RIM, see above) to appraise the individual integrity measurements the conveyed evidence is composed on. The acquisition or representation (data models) of declarative guidance as well as the corresponding evaluation methods are out of the scope of this document.

1.6. Information Elements and Conveyance

TUDA defines a set of information elements (IE) that are created and stored on the Attestor and are intended to be transferred to the Verifier in order to enable appraisal. Each TUDA IE:

- is encoded in the Concise Binary Object Representation (CBOR [RFC7049]) to minimize the volume of data in motion. In this document, the composition of the CBOR data items that represent IE is described using the Concise Data Definition Language, CDDL [I-D.ietf-cbor-cddl]

- that requires a certain freshness is only created/updated when out-dated, which reduces the overall resources required from the Attestor, including the utilization of the hardware root of trust. The IE that have to be created are determined by their age or by specific state changes on the Attestor (e.g. state changes due to a reboot-cycle)

- is only transferred when required, which reduces the amount of data in motion necessary to conduct remote attestation significantly. Only IE that have changed since their last conveyance have to be transferred

- that requires a certain freshness can be reused for multiple remote attestation procedures in the limits of its corresponding

freshness-window, further reducing the load imposed on the Attestor and its corresponding hardware RoT.

1.7. TUDA Objectives

The Time-Based Uni-directional Attestation family of protocols is designed to:

- o increase the confidence in authentication and authorization procedures,
- o address the requirements of constrained-node networks,
- o support interaction models that do not maintain connection-state over time, such as REST architectures [REST],
- o be able to leverage existing management interfaces, such as SNMP [RFC3411]. RESTCONF [RFC8040] or CoMI [I-D.ietf-core-comi] -- and corresponding bindings,
- o support broadcast and multicast schemes (e.g. [IEEE1609]),
- o be able to cope with temporary loss of connectivity, and to
- o provide trustworthy audit logs of past endpoint states.

1.8. Hardware Dependencies

The binding of the attestation scheme used by TUDA to generate the TUDA IE is specific to the methods provided by the hardware RoT used (see above). In this document,expositional text and pseudo-code that is provided as a reference to instantiate the TUDA IE is based on TPM 1.2 and TPM 2.0 operations. The corresponding TPM commands are specified in [TPM12] and [TPM2]. The references to TPM commands and corresponding pseudo-code only serve as guidance to enable a better understanding of the attestation scheme and is intended to encourage the use of any appropriate hardware RoT or equivalent set of functions available to a CPU or Trusted Execution Environment [TEE].

1.9. 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 RFC 2119, BCP 14 [RFC2119].

2. TUDA Core Concept

There are significant differences between conventional bi-directional attestation and TUDA regarding both the information elements conveyed between Attestor and Verifier and the time-frame, in which an attestation can be considered to be fresh (and therefore trustworthy).

In general, remote attestation using a bi-directional communication scheme includes sending a nonce-challenge within a signed attestation token. Using the TPM 1.2 as an example, a corresponding nonce-challenge would be included within the signature created by the TPM_Quote command in order to prove the freshness of the attestation response, see e.g. [PTS].

In contrast, the TUDA protocol uses the combined output of TPM_CertifyInfo and TPM_TickStampBlob. The former provides a proof about the platform's state by creating evidence that a certain key is bound to that state. The latter provides proof that the platform was in the specified state by using the bound key in a time operation. This combination enables a time-based attestation scheme. The approach is based on the concepts introduced in [SCALE] and [SFKE2008].

Each TUDA IE has an individual time-frame, in which it is considered to be fresh (and therefore trustworthy). In consequence, each TUDA IE that composes data in motion is based on different methods of creation.

The freshness properties of a challenge-response based protocol define the point-of-time of attestation between:

- the time of transmission of the nonce, and
- the reception of the corresponding response.

Given the time-based attestation scheme, the freshness property of TUDA is equivalent to that of bi-directional challenge response attestation, if the point-in-time of attestation lies between:

- the transmission of a TUDA time-synchronization token, and
- the typical round-trip time between the Verifier and the Attestor.

The accuracy of this time-frame is defined by two factors:

- the time-synchronization between the Attestor and the TSA. The time between the two tickstamps acquired via the hardware RoT

define the scope of the maximum drift ("left" and "right" in respect to the timeline) to the TSA timestamp, and

- the drift of clocks included in the hardware RoT.

Since the conveyance of TUDA evidence does not rely upon a Verifier provided value (i.e. the nonce), the security guarantees of the protocol only incorporate the TSA and the hardware RoT. In consequence, TUDA evidence can even serve as proof of integrity in audit logs with precise point-in-time guarantees, in contrast to classical attestations.

Appendix A contains guidance on how to utilize a REST architecture.

Appendix B contains guidance on how to create an SNMP binding and a corresponding TUDA-MIB.

Appendix C contains a corresponding YANG module that supports both RESTCONF and CoMI.

Appendix D.2 contains a realization of TUDA using TPM 1.2 primitives.

Appendix D.3 contains a realization of TUDA using TPM 2.0 primitives.

3. Terminology

This document introduces roles, information elements and types required to conduct TUDA and uses terminology (e.g. specific certificate names) typically seen in the context of attestation or hardware security modules.

3.1. Universal Terms

Attestation Identity Key (AIK): a special purpose signature (therefore asymmetric) key that supports identity related operations. The private portion of the key pair is maintained confidential to the entity via appropriate measures (that have an impact on the scope of confidence). The public portion of the key pair may be included in AIK credentials that provide a claim about the entity.

Claim: A piece of information asserted about a subject [RFC4949]. A claim is represented as a name/value pair consisting of a Claim Name and a Claim Value [RFC7519].

In the context of SACM, a claim is also specialized as an attribute/value pair that is intended to be related to a statement [I-D.ietf-sacm-terminology].

Endpoint Attestation: the creation of evidence on the Attestor that provides proof of a set of the endpoints's integrity measurements. This is done by digitally signing a set of PCRs using an AIK shielded by the hardware RoT.

Endpoint Characteristics: the context, composition, configuration, state, and behavior of an endpoint.

Evidence: a trustworthy set of claims about an endpoint's characteristics.

Identity: a set of claims that is intended to be related to an entity.

Integrity Measurements: Metrics of endpoint characteristics (i.e. composition, configuration and state) that affect the confidence in the trustworthiness of an endpoint. Digests of integrity measurements can be stored in shielded locations (i.e. PCR of a TPM).

Reference Integrity Measurements: Signed measurements about the characteristics of an endpoint's characteristics that are provided by a vendor and are intended to be used as declarative guidance [I-D.ietf-sacm-terminology] (e.g. a signed CoSWID).

Trustworthy: the qualities of an endpoint that guarantee a specific behavior and/or endpoint characteristics defined by declarative guidance. Analogously, trustworthiness is the quality of being trustworthy with respect to declarative guidance. Trustworthiness is not an absolute property but defined with respect to an entity, corresponding declarative guidance, and has a scope of confidence.

Trustworthy Endpoint: an endpoint that guarantees trustworthy behavior and/or composition (with respect to certain declarative guidance and a scope of confidence).

Trustworthy Statement: evidence that is trustworthy conveyed by an endpoint that is not necessarily trustworthy.

3.2. Roles

Attestor: the endpoint that is the subject of the attestation to another endpoint.

Verifier: the endpoint that consumes the attestation of another endpoint to conduct a verification.

TSA: a Time Stamp Authority [RFC3161]

3.2.1. General Types

Byte: the now customary synonym for octet

Cert: an X.509 certificate represented as a byte-string

3.2.2. RoT specific terms

PCR: a Platform Configuration Register that is part of a hardware root of trust and is used to securely store and report measurements about security posture

PCR-Hash: a hash value of the security posture measurements stored in a TPM PCR (e.g. regarding running software instances) represented as a byte-string

3.3. Certificates

TSA-CA: the Certificate Authority that provides the certificate for the TSA represented as a Cert

AIK-CA: the Certificate Authority that provides the certificate for the attestation identity key of the TPM. This is the client platform credential for this protocol. It is a placeholder for a specific CA and AIK-Cert is a placeholder for the corresponding certificate, depending on what protocol was used. The specific protocols are out of scope for this document, see also [AIK-Enrollment] and [IEEE802.1AR].

4. Time-Based Uni-Directional Attestation

A Time-Based Uni-Directional Attestation (TUDA) consists of the following seven information elements. They are used to gain assurance of the Attestor's platform configuration at a certain point in time:

TSA Certificate: The certificate of the Time Stamp Authority that is used in a subsequent synchronization protocol token. This certificate is signed by the TSA-CA.

AIK Certificate: A certificate about the Attestation Identity Key (AIK) used. This may or may not also be an [IEEE802.1AR] IDevID or LDevID, depending on their setting of the corresponding identity property. ([AIK-Credential], [AIK-Enrollment]; see Appendix D.2.1.)

Synchronization Token: The reference for attestations are the relative timestanps provided by the hardware RoT. In order to put

attestations into relation with a Real Time Clock (RTC), it is necessary to provide a cryptographic synchronization between these trusted relative timestamps and the regular RTC that is a hardware component of the Attestor. To do so, a synchronization protocol is run with a Time Stamp Authority (TSA).

Restriction Info: The attestation relies on the capability of the hardware RoT to operate on restricted keys. Whenever the PCR values for the machine to be attested change, a new restricted key is created that can only be operated as long as the PCRs remain in their current state.

In order to prove to the Verifier that this restricted temporary key actually has these properties and also to provide the PCR value that it is restricted, the corresponding signing capabilities of the hardware RoT are used. It creates a signed certificate using the AIK about the newly created restricted key.

Measurement Log: Similarly to regular attestations, the Verifier needs a way to reconstruct the PCRs' values in order to estimate the trustworthiness of the device. As such, a list of those elements that were extended into the PCRs is reported. Note though that for certain environments, this step may be optional if a list of valid PCR configurations (in the form of RIM available to the Verifier) exists and no measurement log is required.

Implicit Attestation: The actual attestation is then based upon a signed timestamp provided by the hardware RoT using the restricted temporary key that was certified in the steps above. The signed timestamp provides evidence that at this point in time (with respect to the relative time of the hardware RoT) a certain configuration existed (namely the PCR values associated with the restricted key). Together with the synchronization token this timestamp represented in relative time can then be related to the real-time clock.

Concise SWID tags: As an option to better assess the trustworthiness of an Attestor, a Verifier can request the reference hashes (RIM, which are often referred to as golden measurements) of all started software components to compare them with the entries in the measurement log. References hashes regarding installed (and therefore running) software can be provided by the manufacturer via SWID tags. SWID tags are provided by the Attestor using the Concise SWID representation [I-D.ietf-sacm-coswid] and bundled into a CBOR array (a RIM Manifest). Ideally, the reference hashes include a signature created by the manufacturer of the software to prove their integrity.

These information elements could be sent en bloc, but it is recommended to retrieve them separately to save bandwidth, since these elements have different update cycles. In most cases, retransmitting all seven information elements would result in unnecessary redundancy.

Furthermore, in some scenarios it might be feasible not to store all elements on the Attestor endpoint, but instead they could be retrieved from another location or be pre-deployed to the Verifier. It is also feasible to only store public keys on the Verifier and skip the whole certificate provisioning completely in order to save bandwidth and computation time for certificate verification.

4.1. TUDA Information Elements Update Cycles

An endpoint can be in various states and have various information associated with it during its life cycle. For TUDA, a subset of the states (which can include associated information) that an endpoint and its hardware root of trust can be in, is important to the attestation process. States can be:

- persistent, even after a hard reboot. This includes certificates that are associated with the endpoint itself or with services it relies on.

- volatile to a degree, because they change at the beginning of each boot cycle. This includes the capability of a hardware RoT to provide relative time which provides the basis for the synchronization token and implicit attestation--and which can reset after an endpoint is powered off.

- very volatile, because they change during an uptime cycle (the period of time an endpoint is powered on, starting with its boot). This includes the content of PCRs of a hardware RoT and thereby also the PCR-restricted signing keys used for attestation.

Depending on this "lifetime of state", data has to be transported over the wire, or not. E.g. information that does not change due to a reboot typically has to be transported only once between the Attestor and the Verifier.

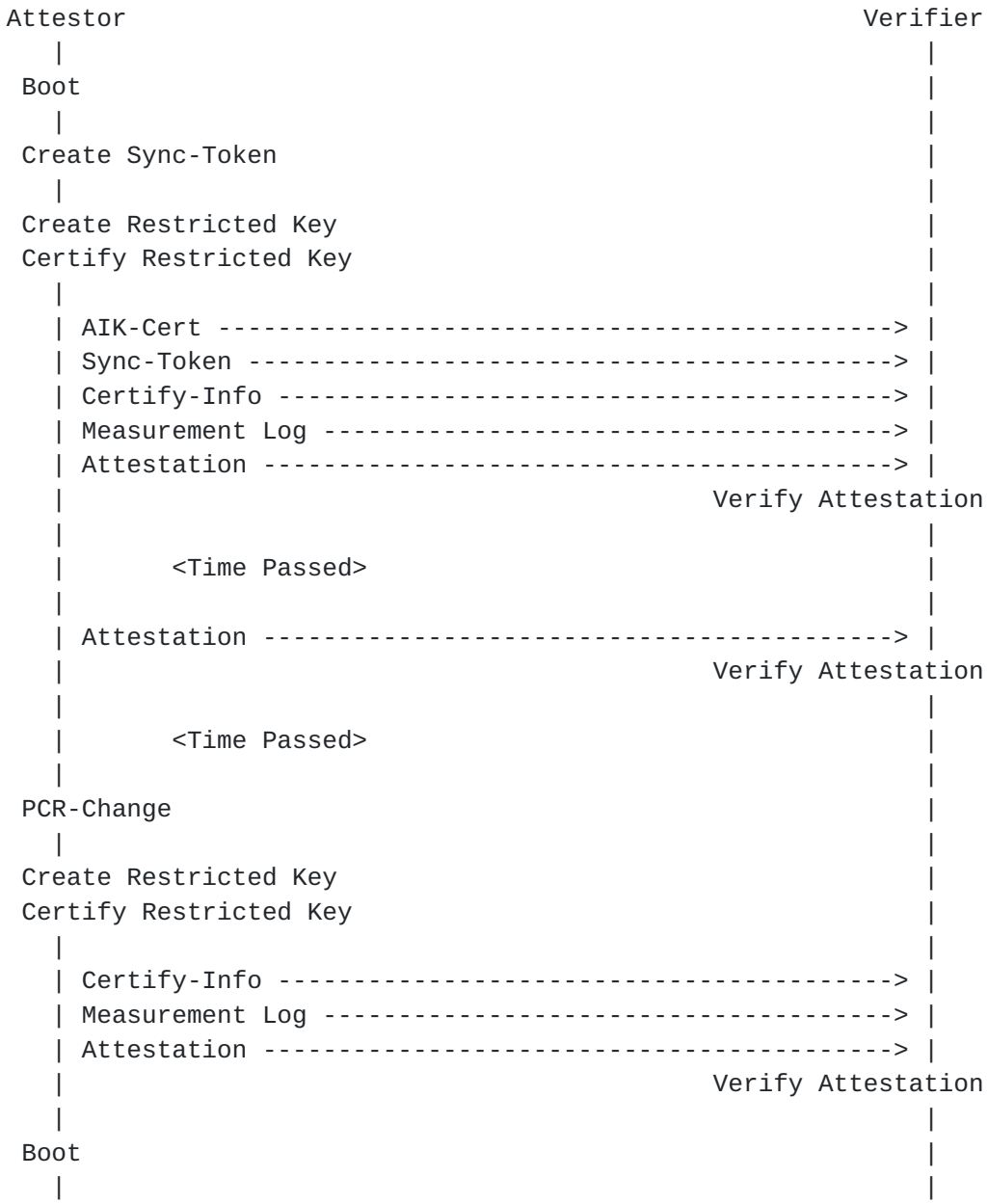
There are three kinds of events that require a renewed attestation:

- The Attestor completes a boot-cycle

- A relevant PCR changes

- Too much time has passed since the last attestation statement

The third event listed above is variable per application use case and also depends on the precision of the clock included in the hardware RoT. For usage scenarios, in which the device would periodically push information to be used in an audit-log, a time-frame of approximately one update per minute should be sufficient in most cases. For those usage scenarios, where Verifiers request (pull) a fresh attestation statement, an implementation could use the hardware RoT continuously to always present the most freshly created results. To save some utilization of the hardware RoT for other purposes, however, a time-frame of once per ten seconds is recommended, which would typically leave about 80% of utilization for other applications.



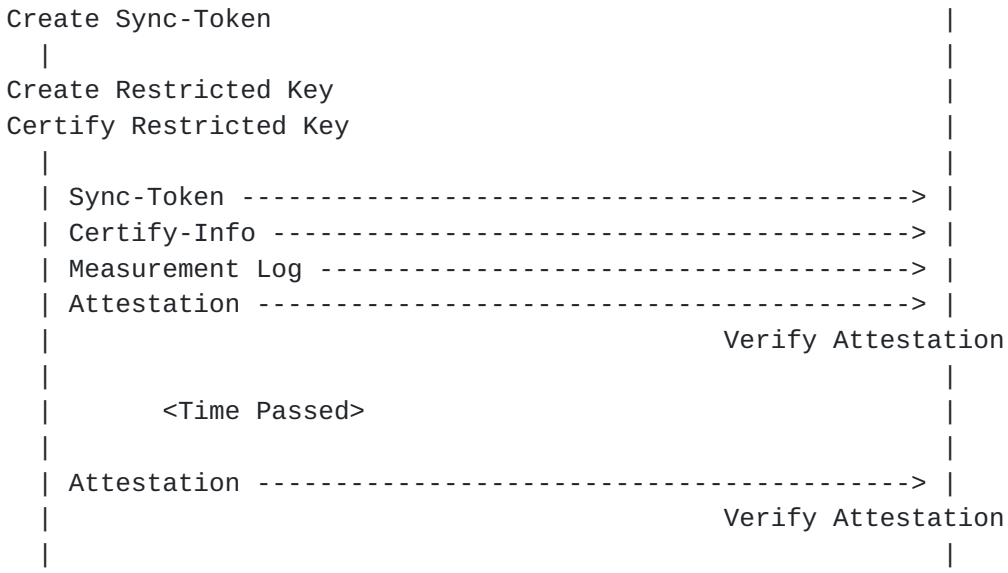


Figure 1: Example sequence of events

5. Sync Base Protocol

The uni-directional approach of TUDA requires evidence on how the TPM time represented in ticks (relative time since boot of the TPM) relates to the standard time provided by the TSA. The Sync Base Protocol (SBP) creates evidence that binds the TPM tick time to the TSA timestamp. The binding information is used by and conveyed via the Sync Token (TUDA IE). There are three actions required to create the content of a Sync Token:

- At a given point in time (called "left"), a signed tickstamp counter value is acquired from the hardware RoT. The hash of counter and signature is used as a nonce in the request directed at the TSA.

- The corresponding response includes a data-structure incorporating the trusted timestamp token and its signature created by the TSA.

- At the point-in-time the response arrives (called "right"), a signed tickstamp counter value is acquired from the hardware RoT again, using a hash of the signed TSA timestamp as a nonce.

The three time-related values -- the relative timestamps provided by the hardware RoT ("left" and "right") and the TSA timestamp -- and their corresponding signatures are aggregated in order to create a corresponding Sync Token to be used as a TUDA Information Element that can be conveyed as evidence to a Verifier.

The drift of a clock incorporated in the hardware RoT that drives the increments of the tick counter constitutes one of the triggers that can initiate a TUDA Information Element Update Cycle in respect to the freshness of the available Sync Token.

content TBD

6. IANA Considerations

This memo includes requests to IANA, including registrations for media type definitions.

TBD

7. Security Considerations

There are Security Considerations. TBD

8. Change Log

Changes from version 04 to I2NSF related document version 00: * Refactored main document to be more technology agnostic * Added first draft of procedures for TPM 2.0 * Improved content consistency and structure of all sections

Changes from version 03 to version 04:

- Refactoring of Introduction, intend, scope and audience
- Added first draft of Sync Base Prootoll section illustrated background for interaction with TSA
- Added YANG module
- Added missing changelog entry

Changes from version 02 to version 03:

- Moved base concept out of Introduction
- First refactoring of Introduction and Concept
- First restructuring of Appendices and improved references

Changes from version 01 to version 02:

- Restructuring of Introduction, highlighting conceptual prerequisites

- Restructuring of Concept to better illustrate differences to hand-shake based attestation and deciding factors regarding freshness properties

- Subsection structure added to Terminology

- Clarification of descriptions of approach (these were the FIXMEs)

- Correction of RestrictionInfo structure: Added missing signature member

Changes from version 00 to version 01:

Major update to the SNMP MIB and added a table for the Concise SWID profile Reference Hashes that provides additional information to be compared with the measurement logs.

9. Contributors

TBD

10. References

10.1. Normative References

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

10.2. Informative References

[AIK-Credential] TCG Infrastructure Working Group, "TCG Credential Profile", 2007, <https://www.trustedcomputinggroup.org/wp-content/uploads/IWG-Credential_Profiles_V1_R1_14.pdf>.

[AIK-Enrollment] TCG Infrastructure Working Group, "A CMC Profile for AIK Certificate Enrollment", 2011, <https://www.trustedcomputinggroup.org/wp-content/uploads/IWG_CMC_Profile_Cert_Enrollment_v1_r7.pdf>.

[I-D.ietf-cbor-cddl] Birkholz, H., Vigano, C., and C. Bormann, "Concise data definition language (CDDL): a notational convention to express CBOR and JSON data structures", draft-ietf-cbor-cddl-07 (work in progress), February 2019.

[I-D.ietf-core-comi]
Veillette, M., Stok, P., Pelov, A., and A. Bierman, "CoAP Management Interface", draft-ietf-core-comi-04 (work in progress), November 2018.

[I-D.ietf-sacm-coswid]
Birkholz, H., Fitzgerald-McKay, J., Schmidt, C., and D. Waltermire, "Concise Software Identifiers", draft-ietf-sacm-coswid-08 (work in progress), November 2018.

[I-D.ietf-sacm-terminology]
Birkholz, H., Lu, J., Strassner, J., Cam-Winget, N., and A. Montville, "Security Automation and Continuous Monitoring (SACM) Terminology", draft-ietf-sacm-terminology-16 (work in progress), December 2018.

[IEEE1609]
IEEE Computer Society, "1609.4-2016 - IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Multi-Channel Operation", IEEE Std 1609.4, 2016.

[IEEE802.1AR]
IEEE Computer Society, "802.1AR-2009 - IEEE Standard for Local and metropolitan area networks - Secure Device Identity", IEEE Std 802.1AR, 2009.

[PRIRA] Coker, G., Guttman, J., Loscocco, P., Herzog, A., Millen, J., O'Hanlon, B., Ramsdell, J., Segall, A., Sheehy, J., and B. Sniffen, "Principles of Remote Attestation", Springer International Journal of Information Security, Vol. 10, pp. 63-81, DOI 10.1007/s10207-011-0124-7, April 2011.

[PTS] TCG TNC Working Group, "TCG Attestation PTS Protocol Binding to TNC IF-M", 2011, <https://www.trustedcomputinggroup.org/wp-content/uploads/IFM_PTS_v1_0_r28.pdf>.

[REST] Fielding, R., "Architectural Styles and the Design of Network-based Software Architectures", Ph.D. Dissertation, University of California, Irvine, 2000, <http://www.ics.uci.edu/~fielding/pubs/dissertation/fielding_dissertation.pdf>.

[RFC1213] McCloghrie, K. and M. Rose, "Management Information Base for Network Management of TCP/IP-based internets: MIB-II", STD 17, RFC 1213, DOI 10.17487/RFC1213, March 1991, <https://www.rfc-editor.org/info/rfc1213>.

[RFC2790] Waldbusser, S. and P. Grillo, "Host Resources MIB", RFC 2790, DOI 10.17487/RFC2790, March 2000, <https://www.rfc-editor.org/info/rfc2790>.

[RFC3161] Adams, C., Cain, P., Pinkas, D., and R. Zuccherato, "Internet X.509 Public Key Infrastructure Time-Stamp Protocol (TSP)", RFC 3161, DOI 10.17487/RFC3161, August 2001, <https://www.rfc-editor.org/info/rfc3161>.

[RFC3411] Harrington, D., Presuhn, R., and B. Wijnen, "An Architecture for Describing Simple Network Management Protocol (SNMP) Management Frameworks", STD 62, RFC 3411, DOI 10.17487/RFC3411, December 2002, <https://www.rfc-editor.org/info/rfc3411>.

[RFC3418] Presuhn, R., Ed., "Management Information Base (MIB) for the Simple Network Management Protocol (SNMP)", STD 62, RFC 3418, DOI 10.17487/RFC3418, December 2002, <https://www.rfc-editor.org/info/rfc3418>.

[RFC4949] Shirey, R., "Internet Security Glossary, Version 2", FYI 36, RFC 4949, DOI 10.17487/RFC4949, August 2007, <https://www.rfc-editor.org/info/rfc4949>.

[RFC6690] Shelby, Z., "Constrained RESTful Environments (CoRE) Link Format", RFC 6690, DOI 10.17487/RFC6690, August 2012, <https://www.rfc-editor.org/info/rfc6690>.

[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>.

[RFC7049] Bormann, C. and P. Hoffman, "Concise Binary Object Representation (CBOR)", RFC 7049, DOI 10.17487/RFC7049, October 2013, <https://www.rfc-editor.org/info/rfc7049>.

[RFC7230] Fielding, R., Ed. and J. Reschke, Ed., "Hypertext Transfer Protocol (HTTP/1.1): Message Syntax and Routing", RFC 7230, DOI 10.17487/RFC7230, June 2014, <https://www.rfc-editor.org/info/rfc7230>.

[RFC7252] Shelby, Z., Hartke, K., and C. Bormann, "The Constrained Application Protocol (CoAP)", RFC 7252, DOI 10.17487/RFC7252, June 2014, <https://www.rfc-editor.org/info/rfc7252>.

[RFC7320] Nottingham, M., "URI Design and Ownership", BCP 190, RFC 7320, DOI 10.17487/RFC7320, July 2014, <https://www.rfc-editor.org/info/rfc7320>.

[RFC7519] Jones, M., Bradley, J., and N. Sakimura, "JSON Web Token (JWT)", RFC 7519, DOI 10.17487/RFC7519, May 2015, <https://www.rfc-editor.org/info/rfc7519>.

[RFC7540] Belshe, M., Peon, R., and M. Thomson, Ed., "Hypertext Transfer Protocol Version 2 (HTTP/2)", RFC 7540, DOI 10.17487/RFC7540, May 2015, <https://www.rfc-editor.org/info/rfc7540>.

[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>.

[SCALE] Fuchs, A., "Improving Scalability for Remote Attestation", Master Thesis (Diplomarbeit), Technische Universitaet Darmstadt, Germany, 2008.

[SFKE2008] Stumpf, F., Fuchs, A., Katzenbeisser, S., and C. Eckert, "Improving the scalability of platform attestation", ACM Proceedings of the 3rd ACM workshop on Scalable trusted computing - STC '08 , page 1-10, DOI 10.1145/1456455.1456457, 2008.

[STD62] "Internet Standard 62", STD 62, RFCs 3411 to 3418, December 2002.

[TCGGLOSS] TCG, "TCG Glossary", 2012, <https://www.trustedcomputinggroup.org/wp-content/uploads/TCG_Glossary_Board-Approved_12.13.2012.pdf>.

[TEE] Global Platform, "TEE System Architecture v1.1, GPD_SPE_009", 2017.

[TPM12] "Information technology -- Trusted Platform Module -- Part 1: Overview", ISO/IEC 11889-1, 2009.

[TPM2] "Trusted Platform Module Library Specification, Family 2.0, Level 00, Revision 01.16 ed., Trusted Computing Group", 2014.

Appendix A. REST Realization

Each of the seven data items is defined as a media type (Section 6). Representations of resources for each of these media types can be retrieved from URIs that are defined by the respective servers [RFC7320]. As can be derived from the URI, the actual retrieval is via one of the HTTPs ([RFC7230], [RFC7540]) or CoAP [RFC7252]. How a client obtains these URIs is dependent on the application; e.g., CoRE Web links [RFC6690] can be used to obtain the relevant URIs from the self-description of a server, or they could be prescribed by a RESTCONF data model [RFC8040].

Appendix B. SNMP Realization

SNMPv3 [STD62] [RFC3411] is widely available on computers and also constrained devices. To transport the TUDA information elements, an SNMP MIB is defined below which encodes each of the seven TUDA information elements into a table. Each row in a table contains a single read-only columnar SNMP object of datatype OCTET-STRING. The values of a set of rows in each table can be concatenated to reconstitute a CBOR-encoded TUDA information element. The Verifier can retrieve the values for each CBOR fragment by using SNMP GetNext requests to "walk" each table and can decode each of the CBOR-encoded data items based on the corresponding CDDL [I-D.ietf-cbor-cddl] definition.

Design Principles:

1. Over time, TUDA attestation values age and should no longer be used. Every table in the TUDA MIB has a primary index with the value of a separate scalar cycle counter object that disambiguates the transition from one attestation cycle to the next.

2. Over time, the measurement log information (for example) may grow large. Therefore, read-only cycle counter scalar objects in all TUDA MIB object groups facilitate more efficient access with SNMP GetNext requests.

3. Notifications are supported by an SNMP trap definition with all of the cycle counters as bindings, to alert a Verifier that a new attestation cycle has occurred (e.g., synchronization data, measurement log, etc. have been updated by adding new rows and possibly deleting old rows).

B.1. Structure of TUDA MIB

The following table summarizes the object groups, tables and their indexes, and conformance requirements for the TUDA MIB:

Group/Table	Cycle	Instance	Fragment	Required
General				x
AIKCert	x	x	x	
TSACert	x	x	x	
SyncToken	x		x	x
Restrict	x			x
Measure	x	x		
VerifyToken	x			x
SWIDTag	x	x	x	

B.1.1. Cycle Index

A tudaV1<Group>CycleIndex is the:

1. first index of a row (element instance or element fragment) in the tudaV1<Group>Table;

2. identifier of an update cycle on the table, when rows were added and/or deleted from the table (bounded by tudaV1<Group>Cycles); and

3. binding in the tudaV1TrapV2Cycles notification for directed polling.

B.1.2. Instance Index

A tudaV1<Group>InstanceIndex is the:

1. second index of a row (element instance or element fragment) in the tudaV1<Group>Table; except for

2. a row in the tudaV1SyncTokenTable (that has only one instance per cycle).

B.1.3. Fragment Index

A tudaV1<Group>FragmentIndex is the:

1. last index of a row (always an element fragment) in the tudaV1<Group>Table; and

2. accomodation for SNMP transport mapping restrictions for large string elements that require fragmentation.

B.2. Relationship to Host Resources MIB

The General group in the TUDA MIB is analogous to the System group in the Host Resources MIB [RFC2790] and provides context information for the TUDA attestation process.

The Verify Token group in the TUDA MIB is analogous to the Device group in the Host MIB and represents the verifiable state of a TPM device and its associated system.

The SWID Tag group (containing a Concise SWID reference hash profile [I-D.ietf-sacm-coswid]) in the TUDA MIB is analogous to the Software Installed and Software Running groups in the Host Resources MIB [RFC2790].

B.3. Relationship to Entity MIB

The General group in the TUDA MIB is analogous to the Entity General group in the Entity MIB v4 [RFC6933] and provides context information for the TUDA attestation process.

The SWID Tag group in the TUDA MIB is analogous to the Entity Logical group in the Entity MIB v4 [RFC6933].

B.4. Relationship to Other MIBs

The General group in the TUDA MIB is analogous to the System group in MIB-II [RFC1213] and the System group in the SNMPv2 MIB [RFC3418] and provides context information for the TUDA attestation process.

B.5. Definition of TUDA MIB

```
<CODE BEGINS>
TUDA-V1-ATTESTATION-MIB DEFINITIONS ::= BEGIN

IMPORTS
    MODULE-IDENTITY, OBJECT-TYPE, Integer32, Counter32,
    enterprises, NOTIFICATION-TYPE
        FROM SNMPv2-SMI                 -- RFC 2578
    MODULE-COMPLIANCE, OBJECT-GROUP, NOTIFICATION-GROUP
        FROM SNMPv2-CONF                -- RFC 2580
    SnmpAdminString
        FROM SNMP-FRAMEWORK-MIB;        -- RFC 3411

tudaV1MIB MODULE-IDENTITY
```

```
        LAST-UPDATED    "201903120000Z" --  12 March 2019
        ORGANIZATION
            "Fraunhofer SIT"
        CONTACT-INFO
            "Andreas Fuchs
            Fraunhofer Institute for Secure Information Technology
            Email: andreas.fuchs@sit.fraunhofer.de

            Henk Birkholz
            Fraunhofer Institute for Secure Information Technology
            Email: henk.birkholz@sit.fraunhofer.de

            Ira E McDonald
            High North Inc
            Email: blueroofmusic@gmail.com

            Carsten Bormann
            Universitaet Bremen TZI
            Email: cabo@tzi.org"

        DESCRIPTION
            "The MIB module for monitoring of time-based unidirectional
            attestation information from a network endpoint system,
            based on the Trusted Computing Group TPM 1.2 definition.

            Copyright (C) High North Inc (2019)."

        REVISION "201903120000Z" -- 12 March 2019
        DESCRIPTION
            "Eighth version, published as draft-birkholz-rats-tuda-00."

        REVISION "201805030000Z" -- 03 May 2018
        DESCRIPTION
            "Seventh version, published as draft-birkholz-i2nsf-tuda-03."

        REVISION "201805020000Z" -- 02 May 2018
        DESCRIPTION
            "Sixth version, published as draft-birkholz-i2nsf-tuda-02."

        REVISION "201710300000Z" -- 30 October 2017
        DESCRIPTION
            "Fifth version, published as draft-birkholz-i2nsf-tuda-01."

        REVISION "201701090000Z" -- 09 January 2017
        DESCRIPTION
            "Fourth version, published as draft-birkholz-i2nsf-tuda-00."

        REVISION "201607080000Z" -- 08 July 2016
```

```
        DESCRIPTION
            "Third version, published as draft-birkholz-tuda-02."

        REVISION "201603210000Z" -- 21 March 2016
        DESCRIPTION
            "Second version, published as draft-birkholz-tuda-01."

        REVISION "201510180000Z" -- 18 October 2015
        DESCRIPTION
            "Initial version, published as draft-birkholz-tuda-00."

            ::= { enterprises fraunhofersit(21616) mibs(1) tudaV1MIB(1) }

    tudaV1MIBNotifications      OBJECT IDENTIFIER ::= { tudaV1MIB 0 }
    tudaV1MIBObjects            OBJECT IDENTIFIER ::= { tudaV1MIB 1 }
    tudaV1MIBConformance        OBJECT IDENTIFIER ::= { tudaV1MIB 2 }

    --
    --  General
    --
    tudaV1General           OBJECT IDENTIFIER ::= { tudaV1MIBObjects 1 }

    tudaV1GeneralCycles OBJECT-TYPE
        SYNTAX      Counter32
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Count of TUDA update cycles that have occurred, i.e.,
            sum of all the individual group cycle counters.

            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1General 1 }

    tudaV1GeneralVersionInfo OBJECT-TYPE
        SYNTAX      SnmpAdminString (SIZE(0..255))
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Version information for TUDA MIB, e.g., specific release
            version of TPM 1.2 base specification and release version
            of TPM 1.2 errata specification and manufacturer and model
            TPM module itself."
        DEFVAL      { "" }
        ::= { tudaV1General 2 }

    --
    --  AIK Cert
    --
```

```
   tudaV1AIKCert           OBJECT IDENTIFIER ::= { tudaV1MIBObjects 2 }

   tudaV1AIKCertCycles OBJECT-TYPE
       SYNTAX      Counter32
       MAX-ACCESS  read-only
       STATUS      current
       DESCRIPTION
           "Count of AIK Certificate chain update cycles that have
           occurred.

           DEFVAL intentionally omitted - counter object."
       ::= { tudaV1AIKCert 1 }

   tudaV1AIKCertTable OBJECT-TYPE
       SYNTAX      SEQUENCE OF TudaV1AIKCertEntry
       MAX-ACCESS  not-accessible
       STATUS      current
       DESCRIPTION
           "A table of fragments of AIK Certificate data."
       ::= { tudaV1AIKCert 2 }

   tudaV1AIKCertEntry OBJECT-TYPE
       SYNTAX      TudaV1AIKCertEntry
       MAX-ACCESS  not-accessible
       STATUS      current
       DESCRIPTION
           "An entry for one fragment of AIK Certificate data."
       INDEX       { tudaV1AIKCertCycleIndex,
                     tudaV1AIKCertInstanceIndex,
                     tudaV1AIKCertFragmentIndex }
       ::= { tudaV1AIKCertTable 1 }

   TudaV1AIKCertEntry ::=
       SEQUENCE {
           tudaV1AIKCertCycleIndex         Integer32,
           tudaV1AIKCertInstanceIndex      Integer32,
           tudaV1AIKCertFragmentIndex      Integer32,
           tudaV1AIKCertData               OCTET STRING
       }

   tudaV1AIKCertCycleIndex OBJECT-TYPE
       SYNTAX      Integer32 (1..2147483647)
       MAX-ACCESS  not-accessible
       STATUS      current
       DESCRIPTION
           "High-order index of this AIK Certificate fragment.
           Index of an AIK Certificate chain update cycle that has
           occurred (bounded by the value of tudaV1AIKCertCycles).
```

```
            DEFVAL intentionally omitted - index object."
        ::= { tudaV1AIKCertEntry 1 }

    tudaV1AIKCertInstanceIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Middle index of this AIK Certificate fragment.
            Ordinal of this AIK Certificate in this chain, where the AIK
            Certificate itself has an ordinal of '1' and higher ordinals
            go *up* the certificate chain to the Root CA.

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1AIKCertEntry 2 }

    tudaV1AIKCertFragmentIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Low-order index of this AIK Certificate fragment.

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1AIKCertEntry 3 }

    tudaV1AIKCertData OBJECT-TYPE
        SYNTAX      OCTET STRING (SIZE(0..1024))
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "A fragment of CBOR encoded AIK Certificate data."
        DEFVAL      { "" }
        ::= { tudaV1AIKCertEntry 4 }

    --
    --  TSA Cert
    --
    tudaV1TSACert           OBJECT IDENTIFIER ::= { tudaV1MIBObjects 3 }

    tudaV1TSACertCycles OBJECT-TYPE
        SYNTAX      Counter32
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Count of TSA Certificate chain update cycles that have
            occurred.
```

```
            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1TSACert 1 }

    tudaV1TSACertTable OBJECT-TYPE
        SYNTAX      SEQUENCE OF TudaV1TSACertEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "A table of fragments of TSA Certificate data."
        ::= { tudaV1TSACert 2 }

    tudaV1TSACertEntry OBJECT-TYPE
        SYNTAX      TudaV1TSACertEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "An entry for one fragment of TSA Certificate data."
        INDEX       { tudaV1TSACertCycleIndex,
                      tudaV1TSACertInstanceIndex,
                      tudaV1TSACertFragmentIndex }
        ::= { tudaV1TSACertTable 1 }

    TudaV1TSACertEntry ::=
        SEQUENCE {
            tudaV1TSACertCycleIndex         Integer32,
            tudaV1TSACertInstanceIndex      Integer32,
            tudaV1TSACertFragmentIndex      Integer32,
            tudaV1TSACertData               OCTET STRING
        }

    tudaV1TSACertCycleIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "High-order index of this TSA Certificate fragment.
            Index of a TSA Certificate chain update cycle that has
            occurred (bounded by the value of tudaV1TSACertCycles).

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1TSACertEntry 1 }

    tudaV1TSACertInstanceIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Middle index of this TSA Certificate fragment.
```

```
            Ordinal of this TSA Certificate in this chain, where the TSA
            Certificate itself has an ordinal of '1' and higher ordinals
            go *up* the certificate chain to the Root CA.

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1TSACertEntry 2 }

    tudaV1TSACertFragmentIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Low-order index of this TSA Certificate fragment.

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1TSACertEntry 3 }

    tudaV1TSACertData OBJECT-TYPE
        SYNTAX      OCTET STRING (SIZE(0..1024))
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "A fragment of CBOR encoded TSA Certificate data."
        DEFVAL      { "" }
        ::= { tudaV1TSACertEntry 4 }

    --
    --  Sync Token
    --
    tudaV1SyncToken         OBJECT IDENTIFIER ::= { tudaV1MIBObjects 4 }

    tudaV1SyncTokenCycles OBJECT-TYPE
        SYNTAX      Counter32
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Count of Sync Token update cycles that have
            occurred.

            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1SyncToken 1 }

    tudaV1SyncTokenInstances OBJECT-TYPE
        SYNTAX      Counter32
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Count of Sync Token instance entries that have
```

```
            been recorded (some entries MAY have been pruned).

            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1SyncToken 2 }

    tudaV1SyncTokenTable OBJECT-TYPE
        SYNTAX      SEQUENCE OF TudaV1SyncTokenEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "A table of fragments of Sync Token data."
        ::= { tudaV1SyncToken 3 }

    tudaV1SyncTokenEntry OBJECT-TYPE
        SYNTAX      TudaV1SyncTokenEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "An entry for one fragment of Sync Token data."
        INDEX       { tudaV1SyncTokenCycleIndex,
                      tudaV1SyncTokenInstanceIndex,
                      tudaV1SyncTokenFragmentIndex }
        ::= { tudaV1SyncTokenTable 1 }

    TudaV1SyncTokenEntry ::=
        SEQUENCE {
            tudaV1SyncTokenCycleIndex       Integer32,
            tudaV1SyncTokenInstanceIndex    Integer32,
            tudaV1SyncTokenFragmentIndex    Integer32,
            tudaV1SyncTokenData             OCTET STRING
        }

    tudaV1SyncTokenCycleIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "High-order index of this Sync Token fragment.
            Index of a Sync Token update cycle that has
            occurred (bounded by the value of tudaV1SyncTokenCycles).

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1SyncTokenEntry 1 }

    tudaV1SyncTokenInstanceIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
```

```
        DESCRIPTION
            "Middle index of this Sync Token fragment.
            Ordinal of this instance of Sync Token data
            (NOT bounded by the value of tudaV1SyncTokenInstances).

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1SyncTokenEntry 2 }

    tudaV1SyncTokenFragmentIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Low-order index of this Sync Token fragment.

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1SyncTokenEntry 3 }

    tudaV1SyncTokenData OBJECT-TYPE
        SYNTAX      OCTET STRING (SIZE(0..1024))
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "A fragment of CBOR encoded Sync Token data."
        DEFVAL      { "" }
        ::= { tudaV1SyncTokenEntry 4 }

    --
    --  Restriction Info
    --
    tudaV1Restrict          OBJECT IDENTIFIER ::= { tudaV1MIBObjects 5 }

    tudaV1RestrictCycles OBJECT-TYPE
        SYNTAX      Counter32
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Count of Restriction Info update cycles that have
            occurred.

            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1Restrict 1 }

    tudaV1RestrictTable OBJECT-TYPE
        SYNTAX      SEQUENCE OF TudaV1RestrictEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
```

```
            "A table of instances of Restriction Info data."
        ::= { tudaV1Restrict 2 }

    tudaV1RestrictEntry OBJECT-TYPE
        SYNTAX      TudaV1RestrictEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "An entry for one instance of Restriction Info data."
        INDEX       { tudaV1RestrictCycleIndex }
        ::= { tudaV1RestrictTable 1 }

    TudaV1RestrictEntry ::=
        SEQUENCE {
            tudaV1RestrictCycleIndex        Integer32,
            tudaV1RestrictData              OCTET STRING
        }

    tudaV1RestrictCycleIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Index of this Restriction Info entry.
            Index of a Restriction Info update cycle that has
            occurred (bounded by the value of tudaV1RestrictCycles).

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1RestrictEntry 1 }


    tudaV1RestrictData OBJECT-TYPE
        SYNTAX      OCTET STRING (SIZE(0..1024))
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "An instance of CBOR encoded Restriction Info data."
        DEFVAL      { "" }
        ::= { tudaV1RestrictEntry 2 }

    --
    --  Measurement Log
    --
    tudaV1Measure           OBJECT IDENTIFIER ::= { tudaV1MIBObjects 6 }

    tudaV1MeasureCycles OBJECT-TYPE
        SYNTAX      Counter32
        MAX-ACCESS  read-only
```

```
        STATUS      current
        DESCRIPTION
            "Count of Measurement Log update cycles that have
            occurred.

            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1Measure 1 }

    tudaV1MeasureInstances OBJECT-TYPE
        SYNTAX      Counter32
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Count of Measurement Log instance entries that have
            been recorded (some entries MAY have been pruned).

            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1Measure 2 }

    tudaV1MeasureTable OBJECT-TYPE
        SYNTAX      SEQUENCE OF TudaV1MeasureEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "A table of instances of Measurement Log data."
        ::= { tudaV1Measure 3 }

    tudaV1MeasureEntry OBJECT-TYPE
        SYNTAX      TudaV1MeasureEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "An entry for one instance of Measurement Log data."
        INDEX       { tudaV1MeasureCycleIndex,
                      tudaV1MeasureInstanceIndex }
        ::= { tudaV1MeasureTable 1 }

    TudaV1MeasureEntry ::=
        SEQUENCE {
            tudaV1MeasureCycleIndex         Integer32,
            tudaV1MeasureInstanceIndex      Integer32,
            tudaV1MeasureData               OCTET STRING
        }

    tudaV1MeasureCycleIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
```

```
        DESCRIPTION
            "High-order index of this Measurement Log entry.
            Index of a Measurement Log update cycle that has
            occurred (bounded by the value of tudaV1MeasureCycles).

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1MeasureEntry 1 }

    tudaV1MeasureInstanceIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Low-order index of this Measurement Log entry.
            Ordinal of this instance of Measurement Log data
            (NOT bounded by the value of tudaV1MeasureInstances).

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1MeasureEntry 2 }

    tudaV1MeasureData OBJECT-TYPE
        SYNTAX      OCTET STRING (SIZE(0..1024))
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "A instance of CBOR encoded Measurement Log data."
        DEFVAL      { "" }
        ::= { tudaV1MeasureEntry 3 }

    --
    --  Verify Token
    --
    tudaV1VerifyToken       OBJECT IDENTIFIER ::= { tudaV1MIBObjects 7 }

    tudaV1VerifyTokenCycles OBJECT-TYPE
        SYNTAX      Counter32
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Count of Verify Token update cycles that have
            occurred.

            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1VerifyToken 1 }

    tudaV1VerifyTokenTable OBJECT-TYPE
        SYNTAX      SEQUENCE OF TudaV1VerifyTokenEntry
        MAX-ACCESS  not-accessible
```

```
        STATUS      current
        DESCRIPTION
            "A table of instances of Verify Token data."
        ::= { tudaV1VerifyToken 2 }

    tudaV1VerifyTokenEntry OBJECT-TYPE
        SYNTAX      TudaV1VerifyTokenEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "An entry for one instance of Verify Token data."
        INDEX       { tudaV1VerifyTokenCycleIndex }
        ::= { tudaV1VerifyTokenTable 1 }

    TudaV1VerifyTokenEntry ::=
        SEQUENCE {
            tudaV1VerifyTokenCycleIndex     Integer32,
            tudaV1VerifyTokenData           OCTET STRING
        }

    tudaV1VerifyTokenCycleIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Index of this instance of Verify Token data.
            Index of a Verify Token update cycle that has
            occurred (bounded by the value of tudaV1VerifyTokenCycles).

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1VerifyTokenEntry 1 }

    tudaV1VerifyTokenData OBJECT-TYPE
        SYNTAX      OCTET STRING (SIZE(0..1024))
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "A instance of CBOR encoded Verify Token data."
        DEFVAL      { "" }
        ::= { tudaV1VerifyTokenEntry 2 }

    --
    --  SWID Tag
    --
    tudaV1SWIDTag           OBJECT IDENTIFIER ::= { tudaV1MIBObjects 8 }

    tudaV1SWIDTagCycles OBJECT-TYPE
        SYNTAX      Counter32
```

```
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "Count of SWID Tag update cycles that have occurred.

            DEFVAL intentionally omitted - counter object."
        ::= { tudaV1SWIDTag 1 }

    tudaV1SWIDTagTable OBJECT-TYPE
        SYNTAX      SEQUENCE OF TudaV1SWIDTagEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "A table of fragments of SWID Tag data."
        ::= { tudaV1SWIDTag 2 }

    tudaV1SWIDTagEntry OBJECT-TYPE
        SYNTAX      TudaV1SWIDTagEntry
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "An entry for one fragment of SWID Tag data."
        INDEX       { tudaV1SWIDTagCycleIndex,
                      tudaV1SWIDTagInstanceIndex,
                      tudaV1SWIDTagFragmentIndex }
        ::= { tudaV1SWIDTagTable 1 }

    TudaV1SWIDTagEntry ::=
        SEQUENCE {
            tudaV1SWIDTagCycleIndex         Integer32,
            tudaV1SWIDTagInstanceIndex      Integer32,
            tudaV1SWIDTagFragmentIndex      Integer32,
            tudaV1SWIDTagData               OCTET STRING
        }

    tudaV1SWIDTagCycleIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "High-order index of this SWID Tag fragment.
            Index of an SWID Tag update cycle that has
            occurred (bounded by the value of tudaV1SWIDTagCycles).

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1SWIDTagEntry 1 }

    tudaV1SWIDTagInstanceIndex OBJECT-TYPE
```

```
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Middle index of this SWID Tag fragment.
            Ordinal of this SWID Tag instance in this update cycle.

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1SWIDTagEntry 2 }

    tudaV1SWIDTagFragmentIndex OBJECT-TYPE
        SYNTAX      Integer32 (1..2147483647)
        MAX-ACCESS  not-accessible
        STATUS      current
        DESCRIPTION
            "Low-order index of this SWID Tag fragment.

            DEFVAL intentionally omitted - index object."
        ::= { tudaV1SWIDTagEntry 3 }

    tudaV1SWIDTagData OBJECT-TYPE
        SYNTAX      OCTET STRING (SIZE(0..1024))
        MAX-ACCESS  read-only
        STATUS      current
        DESCRIPTION
            "A fragment of CBOR encoded SWID Tag data."
        DEFVAL      { "" }
        ::= { tudaV1SWIDTagEntry 4 }

    --
    --  Trap Cycles
    --
    tudaV1TrapV2Cycles NOTIFICATION-TYPE
        OBJECTS {
            tudaV1GeneralCycles,
            tudaV1AIKCertCycles,
            tudaV1TSACertCycles,
            tudaV1SyncTokenCycles,
            tudaV1SyncTokenInstances,
            tudaV1RestrictCycles,
            tudaV1MeasureCycles,
            tudaV1MeasureInstances,
            tudaV1VerifyTokenCycles,
            tudaV1SWIDTagCycles
        }
        STATUS  current
        DESCRIPTION
            "This trap is sent when the value of any cycle or instance
```

```
            counter changes (i.e., one or more tables are updated).

            Note:  The value of sysUpTime in IETF MIB-II (RFC 1213) is
            always included in SNMPv2 traps, per RFC 3416."
        ::= { tudaV1MIBNotifications 1 }

    --
    --  Conformance Information
    --
    tudaV1Compliances           OBJECT IDENTIFIER
        ::= { tudaV1MIBConformance 1 }

    tudaV1ObjectGroups          OBJECT IDENTIFIER
        ::= { tudaV1MIBConformance 2 }

    tudaV1NotificationGroups    OBJECT IDENTIFIER
        ::= { tudaV1MIBConformance 3 }

    --
    --  Compliance Statements
    --
    tudaV1BasicCompliance MODULE-COMPLIANCE
        STATUS  current
        DESCRIPTION
            "An implementation that complies with this module MUST
            implement all of the objects defined in the mandatory
            group tudaV1BasicGroup."
        MODULE  -- this module
        MANDATORY-GROUPS { tudaV1BasicGroup }

        GROUP   tudaV1OptionalGroup
        DESCRIPTION
            "The optional TUDA MIB objects.
            An implementation MAY implement this group."

        GROUP   tudaV1TrapGroup
        DESCRIPTION
            "The TUDA MIB traps.
            An implementation SHOULD implement this group."
        ::= { tudaV1Compliances 1 }

    --
    --  Compliance Groups
    --
    tudaV1BasicGroup OBJECT-GROUP
        OBJECTS {
            tudaV1GeneralCycles,
            tudaV1GeneralVersionInfo,
```

```
            tudaV1SyncTokenCycles,
            tudaV1SyncTokenInstances,
            tudaV1SyncTokenData,
            tudaV1RestrictCycles,
            tudaV1RestrictData,
            tudaV1VerifyTokenCycles,
            tudaV1VerifyTokenData
        }
        STATUS  current
        DESCRIPTION
            "The basic mandatory TUDA MIB objects."
        ::= { tudaV1ObjectGroups 1 }

    tudaV1OptionalGroup OBJECT-GROUP
        OBJECTS {
            tudaV1AIKCertCycles,
            tudaV1AIKCertData,
            tudaV1TSACertCycles,
            tudaV1TSACertData,
            tudaV1MeasureCycles,
            tudaV1MeasureInstances,
            tudaV1MeasureData,
            tudaV1SWIDTagCycles,
            tudaV1SWIDTagData
        }
        STATUS  current
        DESCRIPTION
            "The optional TUDA MIB objects."
        ::= { tudaV1ObjectGroups 2 }

    tudaV1TrapGroup NOTIFICATION-GROUP
        NOTIFICATIONS { tudaV1TrapV2Cycles }
        STATUS      current
        DESCRIPTION
            "The recommended TUDA MIB traps - notifications."
        ::= { tudaV1NotificationGroups 1 }

    END
    <CODE ENDS>
```

Appendix C. YANG Realization

```
<CODE BEGINS>
module TUDA-V1-ATTESTATION-MIB {

  namespace "urn:ietf:params:xml:ns:yang:smiv2:TUDA-V1-ATTESTATION-MIB";
  prefix "tuda-v1";
```

```
  import SNMP-FRAMEWORK-MIB { prefix "snmp-framework"; }
  import yang-types         { prefix "yang"; }

  organization
   "Fraunhofer SIT";

  contact
   "Andreas Fuchs
    Fraunhofer Institute for Secure Information Technology
    Email: andreas.fuchs@sit.fraunhofer.de

    Henk Birkholz
    Fraunhofer Institute for Secure Information Technology
    Email: henk.birkholz@sit.fraunhofer.de

    Ira E McDonald
    High North Inc
    Email: blueroofmusic@gmail.com

    Carsten Bormann
    Universitaet Bremen TZI
    Email: cabo@tzi.org";

  description
   "The MIB module for monitoring of time-based unidirectional
    attestation information from a network endpoint system,
    based on the Trusted Computing Group TPM 1.2 definition.

    Copyright (C) High North Inc (2017).";

  revision "2017-10-30" {
    description
     "Fifth version, published as draft-birkholz-tuda-04.";
    reference
     "draft-birkholz-tuda-04";
  }
  revision "2017-01-09" {
    description
     "Fourth version, published as draft-birkholz-tuda-03.";
    reference
     "draft-birkholz-tuda-03";
  }
  revision "2016-07-08" {
    description
     "Third version, published as draft-birkholz-tuda-02.";
    reference
     "draft-birkholz-tuda-02";
  }
```

```
  revision "2016-03-21" {
    description
     "Second version, published as draft-birkholz-tuda-01.";
    reference
     "draft-birkholz-tuda-01";
  }
  revision "2015-10-18" {
    description
     "Initial version, published as draft-birkholz-tuda-00.";
    reference
     "draft-birkholz-tuda-00";
  }

  container tudaV1General {
  description
    "TBD";

    leaf tudaV1GeneralCycles {
      type yang:counter32;
      config false;
      description
       "Count of TUDA update cycles that have occurred, i.e.,
        sum of all the individual group cycle counters.

        DEFVAL intentionally omitted - counter object.";
    }

    leaf tudaV1GeneralVersionInfo {
      type snmp-framework:SnmpAdminString {
        length "0..255";
      }
      config false;
      description
       "Version information for TUDA MIB, e.g., specific release
        version of TPM 1.2 base specification and release version
        of TPM 1.2 errata specification and manufacturer and model
        TPM module itself.";
    }
  }

  container tudaV1AIKCert {
  description
    "TBD";

    leaf tudaV1AIKCertCycles {
      type yang:counter32;
      config false;
      description
```

```
       "Count of AIK Certificate chain update cycles that have
        occurred.

        DEFVAL intentionally omitted - counter object.";
    }


    /* XXX table comments here XXX */

    list tudaV1AIKCertEntry {

      key "tudaV1AIKCertCycleIndex tudaV1AIKCertInstanceIndex
           tudaV1AIKCertFragmentIndex";
        config false;
      description
       "An entry for one fragment of AIK Certificate data.";


      leaf tudaV1AIKCertCycleIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "High-order index of this AIK Certificate fragment.
          Index of an AIK Certificate chain update cycle that has
          occurred (bounded by the value of tudaV1AIKCertCycles).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1AIKCertInstanceIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Middle index of this AIK Certificate fragment.
          Ordinal of this AIK Certificate in this chain, where the AIK
          Certificate itself has an ordinal of '1' and higher ordinals
          go *up* the certificate chain to the Root CA.

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1AIKCertFragmentIndex {
        type int32 {
          range "1..2147483647";
```

```
        }
        config false;
        description
         "Low-order index of this AIK Certificate fragment.

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1AIKCertData {
        type binary {
          length "0..1024";
        }
        config false;
        description
         "A fragment of CBOR encoded AIK Certificate data.";
      }
    }
  }

  container tudaV1TSACert {
  description
    "TBD";

    leaf tudaV1TSACertCycles {
      type yang:counter32;
      config false;
      description
       "Count of TSA Certificate chain update cycles that have
        occurred.

        DEFVAL intentionally omitted - counter object.";
    }


    /* XXX table comments here XXX */

    list tudaV1TSACertEntry {

      key "tudaV1TSACertCycleIndex tudaV1TSACertInstanceIndex
           tudaV1TSACertFragmentIndex";
      config false;
      description
       "An entry for one fragment of TSA Certificate data.";


      leaf tudaV1TSACertCycleIndex {
        type int32 {
          range "1..2147483647";
```

```
        }
        config false;
        description
         "High-order index of this TSA Certificate fragment.
          Index of a TSA Certificate chain update cycle that has
          occurred (bounded by the value of tudaV1TSACertCycles).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1TSACertInstanceIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Middle index of this TSA Certificate fragment.
          Ordinal of this TSA Certificate in this chain, where the TSA
          Certificate itself has an ordinal of '1' and higher ordinals
          go *up* the certificate chain to the Root CA.

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1TSACertFragmentIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Low-order index of this TSA Certificate fragment.

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1TSACertData {
        type binary {
          length "0..1024";
        }
        config false;
        description
         "A fragment of CBOR encoded TSA Certificate data.";
      }
    }
  }

  container tudaV1SyncToken {
  description
```

```
    "TBD";

    leaf tudaV1SyncTokenCycles {
      type yang:counter32;
      config false;
      description
       "Count of Sync Token update cycles that have
        occurred.

        DEFVAL intentionally omitted - counter object.";
    }

    leaf tudaV1SyncTokenInstances {
      type yang:counter32;
      config false;
      description
       "Count of Sync Token instance entries that have
        been recorded (some entries MAY have been pruned).

        DEFVAL intentionally omitted - counter object.";
    }

    list tudaV1SyncTokenEntry {

      key "tudaV1SyncTokenCycleIndex
           tudaV1SyncTokenInstanceIndex
           tudaV1SyncTokenFragmentIndex";
      config false;
      description
       "An entry for one fragment of Sync Token data.";


      leaf tudaV1SyncTokenCycleIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "High-order index of this Sync Token fragment.
          Index of a Sync Token update cycle that has
          occurred (bounded by the value of tudaV1SyncTokenCycles).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1SyncTokenInstanceIndex {
        type int32 {
          range "1..2147483647";
```

```
        }
        config false;
        description
         "Middle index of this Sync Token fragment.
          Ordinal of this instance of Sync Token data
          (NOT bounded by the value of tudaV1SyncTokenInstances).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1SyncTokenFragmentIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Low-order index of this Sync Token fragment.

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1SyncTokenData {
        type binary {
          length "0..1024";
        }
        config false;
        description
         "A fragment of CBOR encoded Sync Token data.";
      }
    }
  }

  container tudaV1Restrict {
  description
    "TBD";

    leaf tudaV1RestrictCycles {
      type yang:counter32;
      config false;
      description
       "Count of Restriction Info update cycles that have
        occurred.

        DEFVAL intentionally omitted - counter object.";
    }


    /* XXX table comments here XXX */
```

```
    list tudaV1RestrictEntry {

      key "tudaV1RestrictCycleIndex";
      config false;
      description
       "An entry for one instance of Restriction Info data.";


      leaf tudaV1RestrictCycleIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Index of this Restriction Info entry.
          Index of a Restriction Info update cycle that has
          occurred (bounded by the value of tudaV1RestrictCycles).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1RestrictData {
        type binary {
          length "0..1024";
        }
        config false;
        description
         "An instance of CBOR encoded Restriction Info data.";
      }
    }
  }

  container tudaV1Measure {
  description
    "TBD";

    leaf tudaV1MeasureCycles {
      type yang:counter32;
      config false;
      description
       "Count of Measurement Log update cycles that have
        occurred.

        DEFVAL intentionally omitted - counter object.";
    }

    leaf tudaV1MeasureInstances {
      type yang:counter32;
```

```
      config false;
      description
       "Count of Measurement Log instance entries that have
        been recorded (some entries MAY have been pruned).

        DEFVAL intentionally omitted - counter object.";
    }

    list tudaV1MeasureEntry {

      key "tudaV1MeasureCycleIndex tudaV1MeasureInstanceIndex";
      config false;
      description
       "An entry for one instance of Measurement Log data.";


      leaf tudaV1MeasureCycleIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "High-order index of this Measurement Log entry.
          Index of a Measurement Log update cycle that has
          occurred (bounded by the value of tudaV1MeasureCycles).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1MeasureInstanceIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Low-order index of this Measurement Log entry.
          Ordinal of this instance of Measurement Log data
          (NOT bounded by the value of tudaV1MeasureInstances).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1MeasureData {
        type binary {
          length "0..1024";
        }
        config false;
        description
```

```
        "A instance of CBOR encoded Measurement Log data.";
      }
    }
  }

  container tudaV1VerifyToken {
  description
    "TBD";

    leaf tudaV1VerifyTokenCycles {
      type yang:counter32;
      config false;
      description
       "Count of Verify Token update cycles that have
        occurred.

        DEFVAL intentionally omitted - counter object.";
    }


    /* XXX table comments here XXX */

    list tudaV1VerifyTokenEntry {

      key "tudaV1VerifyTokenCycleIndex";
      config false;
      description
       "An entry for one instance of Verify Token data.";


      leaf tudaV1VerifyTokenCycleIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Index of this instance of Verify Token data.
          Index of a Verify Token update cycle that has
          occurred (bounded by the value of tudaV1VerifyTokenCycles).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1VerifyTokenData {
        type binary {
          length "0..1024";
        }
        config false;
```

```
        description
         "A instanc-V1-ATTESTATION-MIB.yang
      }
    }
  }

  container tudaV1SWIDTag {
  description
    "see CoSWID and YANG SIWD module for now"

    leaf tudaV1SWIDTagCycles {
      type yang:counter32;
      config false;
      description
       "Count of SWID Tag update cycles that have occurred.

        DEFVAL intentionally omitted - counter object.";
    }

    list tudaV1SWIDTagEntry {

      key "tudaV1SWIDTagCycleIndex tudaV1SWIDTagInstanceIndex
           tudaV1SWIDTagFragmentIndex";
      config false;
      description
       "An entry for one fragment of SWID Tag data.";


      leaf tudaV1SWIDTagCycleIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "High-order index of this SWID Tag fragment.
          Index of an SWID Tag update cycle that has
          occurred (bounded by the value of tudaV1SWIDTagCycles).

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1SWIDTagInstanceIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Middle index of this SWID Tag fragment.
```

```
          Ordinal of this SWID Tag instance in this update cycle.

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1SWIDTagFragmentIndex {
        type int32 {
          range "1..2147483647";
        }
        config false;
        description
         "Low-order index of this SWID Tag fragment.

          DEFVAL intentionally omitted - index object.";
      }

      leaf tudaV1SWIDTagData {
        type binary {
          length "0..1024";
        }
        config false;
        description
         "A fragment of CBOR encoded SWID Tag data.";
      }
    }
  }

  notification tudaV1TrapV2Cycles {
    description
     "This trap is sent when the value of any cycle or instance
      counter changes (i.e., one or more tables are updated).

      Note:  The value of sysUpTime in IETF MIB-II (RFC 1213) is
      always included in SNMPv2 traps, per RFC 3416.";

    container tudaV1TrapV2Cycles-tudaV1GeneralCycles {
      description
       "TPD"
      leaf tudaV1GeneralCycles {
        type yang:counter32;
        description
         "Count of TUDA update cycles that have occurred, i.e.,
          sum of all the individual group cycle counters.

          DEFVAL intentionally omitted - counter object.";
      }
    }
```

```
    container tudaV1TrapV2Cycles-tudaV1AIKCertCycles {
      description
       "TPD"
      leaf tudaV1AIKCertCycles {
        type yang:counter32;
        description
         "Count of AIK Certificate chain update cycles that have
          occurred.

          DEFVAL intentionally omitted - counter object.";
      }
    }

    container tudaV1TrapV2Cycles-tudaV1TSACertCycles {
      description
       "TPD"
      leaf tudaV1TSACertCycles {
        type yang:counter32;
        description
         "Count of TSA Certificate chain update cycles that have
          occurred.

          DEFVAL intentionally omitted - counter object.";
      }
    }

    container tudaV1TrapV2Cycles-tudaV1SyncTokenCycles {
      description
       "TPD"
      leaf tudaV1SyncTokenCycles {
        type yang:counter32;
        description
         "Count of Sync Token update cycles that have
          occurred.

          DEFVAL intentionally omitted - counter object.";
      }
    }

    container tudaV1TrapV2Cycles-tudaV1SyncTokenInstances {
      description
       "TPD"
      leaf tudaV1SyncTokenInstances {
        type yang:counter32;
        description
         "Count of Sync Token instance entries that have
          been recorded (some entries MAY have been pruned).
```

```
          DEFVAL intentionally omitted - counter object.";
      }
    }

    container tudaV1TrapV2Cycles-tudaV1RestrictCycles {
      description
       "TPD"
      leaf tudaV1RestrictCycles {
        type yang:counter32;
        description
         "Count of Restriction Info update cycles that have
          occurred.

          DEFVAL intentionally omitted - counter object.";
      }
    }

    container tudaV1TrapV2Cycles-tudaV1MeasureCycles {
      description
       "TPD"
      leaf tudaV1MeasureCycles {
        type yang:counter32;
        description
         "Count of Measurement Log update cycles that have
          occurred.

          DEFVAL intentionally omitted - counter object.";
      }
    }

    container tudaV1TrapV2Cycles-tudaV1MeasureInstances {
      description
       "TPD"
      leaf tudaV1MeasureInstances {
        type yang:counter32;
        description
         "Count of Measurement Log instance entries that have
          been recorded (some entries MAY have been pruned).

          DEFVAL intentionally omitted - counter object.";
      }
    }

    container tudaV1TrapV2Cycles-tudaV1VerifyTokenCycles {
      description
       "TPD"
      leaf tudaV1VerifyTokenCycles {
        type yang:counter32;
```

```
        description
         "Count of Verify Token update cycles that have
          occurred.

          DEFVAL intentionally omitted - counter object.";
      }
    }

    container tudaV1TrapV2Cycles-tudaV1SWIDTagCycles {
      description
       "TPD"
      leaf tudaV1SWIDTagCycles {
        type yang:counter32;
        description
         "Count of SWID Tag update cycles that have occurred.

          DEFVAL intentionally omitted - counter object.";
      }
    }

  }
}
<CODE ENDS>
```

Appendix D. Realization with TPM functions

D.1. TPM Functions

The following TPM structures, resources and functions are used within this approach. They are based upon the TPM specifications [TPM12] and [TPM2].

D.1.1. Tick-Session and Tick-Stamp

On every boot, the TPM initializes a new Tick-Session. Such a tick-session consists of a nonce that is randomly created upon each boot to identify the current boot-cycle - the phase between boot-time of the device and shutdown or power-off - and prevent replaying of old tick-session values. The TPM uses its internal entropy source that guarantees virtually no collisions of the nonce values between two of such boot cycles.

It further includes an internal timer that is being initialize to Zero on each reboot. From this point on, the TPM increments this timer continuously based upon its internal secure clocking information until the device is powered down or set to sleep. By its hardware design, the TPM will detect attacks on any of those properties.

The TPM offers the function TPM_TickStampBlob, which allows the TPM to create a signature over the current tick-session and two externally provided input values. These input values are designed to serve as a nonce and as payload data to be included in a TickStampBlob: TickstampBlob := sig(TPM-key, currentTicks || nonce || externalData).

As a result, one is able to proof that at a certain point in time (relative to the tick-session) after the provisioning of a certain nonce, some certain externalData was known and provided to the TPM. If an approach however requires no input values or only one input value (such as the use in this document) the input values can be set to well-known value. The convention used within TCG specifications and within this document is to use twenty bytes of zero h'0000000000000000000000000000000000000000' as well-known value.

D.1.2. Platform Configuration Registers (PCRs)

The TPM is a secure cryptoprocessor that provides the ability to store measurements and metrics about an endpoint's configuration and state in a secure, tamper-proof environment. Each of these security relevant metrics can be stored in a volatile Platform Configuration Register (PCR) inside the TPM. These measurements can be conducted at any point in time, ranging from an initial BIOS boot-up sequence to measurements taken after hundreds of hours of uptime.

The initial measurement is triggered by the Platforms so-called pre-BIOS or ROM-code. It will conduct a measurement of the first loadable pieces of code; i.e.\ the BIOS. The BIOS will in turn measure its Option ROMs and the BootLoader, which measures the OS-Kernel, which in turn measures its applications. This describes a so-called measurement chain. This typically gets recorded in a so-called measurement log, such that the values of the PCRs can be reconstructed from the individual measurements for validation.

Via its PCRs, a TPM provides a Root of Trust that can, for example, support secure boot or remote attestation. The attestation of an endpoint's identity or security posture is based on the content of an TPM's PCRs (platform integrity measurements).

D.1.3. PCR restricted Keys

Every key inside the TPM can be restricted in such a way that it can only be used if a certain set of PCRs are in a predetermined state. For key creation the desired state for PCRs are defined via the PCRInfo field inside the keyInfo parameter. Whenever an operation using this key is performed, the TPM first checks whether the PCRs

are in the correct state. Otherwise the operation is denied by the TPM.

D.1.4. CertifyInfo

The TPM offers a command to certify the properties of a key by means of a signature using another key. This includes especially the keyInfo which in turn includes the PCRInfo information used during key creation. This way, a third party can be assured about the fact that a key is only usable if the PCRs are in a certain state.

D.2. IE Generation Procedures for TPM 1.2

D.2.1. AIK and AIK Certificate

Attestations are based upon a cryptographic signature performed by the TPM using a so-called Attestation Identity Key (AIK). An AIK has the properties that it cannot be exported from a TPM and is used for attestations. Trust in the AIK is established by an X.509 Certificate emitted by a Certificate Authority. The AIK certificate is either provided directly or via a so-called PrivacyCA [AIK-Enrollment].

This element consists of the AIK certificate that includes the AIK's public key used during verification as well as the certificate chain up to the Root CA for validation of the AIK certificate itself.

```
TUDA-Cert = [AIK-Cert, TSA-Cert]; maybe split into two for SNMP
AIK-Cert = Cert
TSA-Cert = Cert
```

Figure 2: TUDA-Cert element in CDDL

The TSA-Cert is a standard certificate of the TSA.

The AIK-Cert may be provisioned in a secure environment using standard means or it may follow the PrivacyCA protocols. Figure 3 gives a rough sketch of this protocol. See [AIK-Enrollment] for more information.

The X.509 Certificate is built from the AIK public key and the corresponding PKCS #7 certificate chain, as shown in Figure 3.

Required TPM functions:

```
| create_AIK_Cert(...) = {
|   AIK = TPM_MakeIdentity()
|   IdReq = CollateIdentityRequest(AIK,EK)
|   IdRes = Call(AIK-CA, IdReq)
|   AIK-Cert = TPM_ActivateIdentity(AIK, IdRes)
| }
|
| /* Alternative */
|
| create_AIK_Cert(...) = {
|   AIK = TPM_CreateWrapKey(Identity)
|   AIK-Cert = Call(AIK-CA, AIK.pubkey)
| }
```

Figure 3: Creating the TUDA-Cert element

D.2.2. Synchronization Token

The reference for Attestations are the Tick-Sessions of the TPM. In order to put Attestations into relation with a Real Time Clock (RTC), it is necessary to provide a cryptographic synchronization between the tick session and the RTC. To do so, a synchronization protocol is run with a Time Stamp Authority (TSA) that consists of three steps:

- The TPM creates a TickStampBlob using the AIK
- This TickstampBlob is used as nonce to the Timestamp of the TSA
- Another TickStampBlob with the AIK is created using the TSA's Timestamp a nonce

The first TickStampBlob is called "left" and the second "right" in a reference to their position on a time-axis.

These three elements, with the TSA's certificate factored out, form the synchronization token

```
TUDA-Synctoken = [
  left: TickStampBlob-Output,
  timestamp: TimeStampToken,
  right: TickStampBlob-Output,
]

TimeStampToken = bytes ; RFC 3161

TickStampBlob-Output = [
  currentTicks: TPM-CURRENT-TICKS,
  sig: bytes,
]

TPM-CURRENT-TICKS = [
  currentTicks: uint
  ? (
    tickRate: uint
    tickNonce: TPM-NONCE
  )
]
; Note that TickStampBlob-Output "right" can omit the values for
;   tickRate and tickNonce since they are the same as in "left"

TPM-NONCE = bytes .size 20
```

Figure 4: TUDA-Sync element in CDDL

Required TPM functions:

```
| dummyDigest = h'0000000000000000000000000000000000000000'
| dummyNonce = dummyDigest
|
| create_sync_token(AIKHandle, TSA) = {
|   ts_left = TPM_TickStampBlob(
|       keyHandle = AIK_Handle,      /*TPM_KEY_HANDLE*/
|       antiReplay = dummyNonce,     /*TPM_NONCE*/
|       digestToStamp = dummyDigest  /*TPM_DIGEST*/)
|
|   ts = TSA_Timestamp(TSA, nonce = hash(ts_left))
|
|   ts_right = TPM_TickStampBlob(
|       keyHandle = AIK_Handle,      /*TPM_KEY_HANDLE*/
|       antiReplay = dummyNonce,     /*TPM_NONCE*/
|       digestToStamp = hash(ts))    /*TPM_DIGEST*/
|
|   TUDA-SyncToken = [[ts_left.ticks, ts_left.sig], ts,
|                     [ts_right.ticks.currentTicks, ts_right.sig]]
|   /* Note: skip the nonce and tickRate field for ts_right.ticks */
| }
```

Figure 5: Creating the Sync-Token element

D.2.3. RestrictionInfo

The attestation relies on the capability of the TPM to operate on restricted keys. Whenever the PCR values for the machine to be attested change, a new restricted key is created that can only be operated as long as the PCRs remain in their current state.

In order to prove to the Verifier that this restricted temporary key actually has these properties and also to provide the PCR value that it is restricted, the TPM command TPM_CertifyInfo is used. It creates a signed certificate using the AIK about the newly created restricted key.

This token is formed from the list of:

- PCR list,
- the newly created restricted public key, and
- the certificate.

```
TUDA-RestrictionInfo = [Composite,
                        restrictedKey_Pub: Pubkey,
                        CertifyInfo]
```

```
PCRSelection = bytes .size (2..4) ; used as bit string

Composite = [
  bitmask: PCRSelection,
  values: [*PCR-Hash],
]

Pubkey = bytes ; may be extended to COSE pubkeys

CertifyInfo = [
  TPM-CERTIFY-INFO,
  sig: bytes,
]

TPM-CERTIFY-INFO = [
  ; we don't encode TPM-STRUCT-VER:
  ; these are 4 bytes always equal to h'01010000'
  keyUsage: uint, ; 4byte? 2byte?
  keyFlags: bytes .size 4, ; 4byte
  authDataUsage: uint, ; 1byte (enum)
  algorithmParms: TPM-KEY-PARMS,
  pubkeyDigest: Hash,
  ; we don't encode TPM-NONCE data, which is 20 bytes, all zero
  parentPCRStatus: bool,
  ; no need to encode pcrinfosize
  pcrinfo: TPM-PCR-INFO,        ; we have exactly one
]

TPM-PCR-INFO = [
    pcrSelection: PCRSelection; /* TPM_PCR_SELECTION */
    digestAtRelease: PCR-Hash;  /* TPM_COMPOSITE_HASH */
    digestAtCreation: PCR-Hash; /* TPM_COMPOSITE_HASH */
]

TPM-KEY-PARMS = [
  ; algorithmID: uint, ; <= 4 bytes -- not encoded, constant for TPM1.2
  encScheme: uint, ; <= 2 bytes
  sigScheme: uint, ; <= 2 bytes
  parms: TPM-RSA-KEY-PARMS,
]

TPM-RSA-KEY-PARMS = [
  ; "size of the RSA key in bits":
  keyLength: uint
  ; "number of prime factors used by this RSA key":
  numPrimes: uint
  ; "This SHALL be the size of the exponent":
  exponentSize: null / uint / biguint
```

```
   ; "If the key is using the default exponent then the exponentSize
   ; MUST be 0" -> we represent this case as null
 ]
```

Figure 6: TUDA-Key element in CDDL

Required TPM functions:

```
| dummyDigest = h'0000000000000000000000000000000000000000'
| dummyNonce = dummyDigest
|
| create_Composite
|
| create_restrictedKey_Pub(pcrsel) = {
|   PCRInfo = {pcrSelection = pcrsel,
|              digestAtRelease = hash(currentValues(pcrSelection))
|              digestAtCreation = dummyDigest}
|   / * PCRInfo is a TPM_PCR_INFO and thus also a TPM_KEY */
|
|   wk = TPM_CreateWrapKey(keyInfo = PCRInfo)
|   wk.keyInfo.pubKey
| }
|
| create_TPM-Certify-Info = {
|   CertifyInfo = TPM_CertifyKey(
|       certHandle = AIK,          /* TPM_KEY_HANDLE */
|       keyHandle = wk,            /* TPM_KEY_HANDLE */
|       antiReply = dummyNonce)    /* TPM_NONCE */
|
|   CertifyInfo.strip()
|   /* Remove those values that are not needed */
| }
```

Figure 7: Creating the pubkey

D.2.4. Measurement Log

Similarly to regular attestations, the Verifier needs a way to reconstruct the PCRs' values in order to estimate the trustworthiness of the device. As such, a list of those elements that were extended into the PCRs is reported. Note though that for certain environments, this step may be optional if a list of valid PCR configurations exists and no measurement log is required.

```
TUDA-Measurement-Log = [*PCR-Event]
PCR-Event = [
  type: PCR-Event-Type,
  pcr: uint,
  template-hash: PCR-Hash,
  filedata-hash: tagged-hash,
  pathname: text; called filename-hint in ima (non-ng)
]

PCR-Event-Type = &(
  bios: 0
  ima: 1
  ima-ng: 2
)

; might want to make use of COSE registry here
; however, that might never define a value for sha1
tagged-hash /= [sha1: 0, bytes .size 20]
tagged-hash /= [sha256: 1, bytes .size 32]
```

D.2.5. Implicit Attestation

The actual attestation is then based upon a TickStampBlob using the restricted temporary key that was certified in the steps above. The TPM-Tickstamp is executed and thereby provides evidence that at this point in time (with respect to the TPM internal tick-session) a certain configuration existed (namely the PCR values associated with the restricted key). Together with the synchronization token this tick-related timing can then be related to the real-time clock.

This element consists only of the TPM_TickStampBlock with no nonce.

```
TUDA-Verifytoken = TickStampBlob-Output
```

Figure 8: TUDA-Verify element in CDDL

Required TPM functions:

```
| imp_att = TPM_TickStampBlob(
|     keyHandle = restrictedKey_Handle,     /*TPM_KEY_HANDLE*/
|     antiReplay = dummyNonce,              /*TPM_NONCE*/
|     digestToStamp = dummyDigest)          /*TPM_DIGEST*/
|
| VerifyToken = imp_att
```

Figure 9: Creating the Verify Token

D.2.6. Attestation Verification Approach

The seven TUDA information elements transport the essential content that is required to enable verification of the attestation statement at the Verifier. The following listings illustrate the verification algorithm to be used at the Verifier in pseudocode. The pseudocode provided covers the entire verification task. If only a subset of TUDA elements changed (see Section 4.1), only the corresponding code listings need to be re-executed.

```
| TSA_pub = verifyCert(TSA-CA, Cert.TSA-Cert)
| AIK_pub = verifyCert(AIK-CA, Cert.AIK-Cert)
```

Figure 10: Verification of Certificates

```
| ts_left = Synctoken.left
| ts_right = Synctoken.right
|
| /* Reconstruct ts_right's omitted values; Alternatively assert == */
| ts_right.currentTicks.tickRate = ts_left.currentTicks.tickRate
| ts_right.currentTicks.tickNonce = ts_left.currentTicks.tickNonce
|
| ticks_left = ts_left.currentTicks
| ticks_right = ts_right.currentTicks
|
| /* Verify Signatures */
| verifySig(AIK_pub, dummyNonce || dummyDigest || ticks_left)
| verifySig(TSA_pub, hash(ts_left) || timestamp.time)
| verifySig(AIK_pub, dummyNonce || hash(timestamp) || ticks_right)
|
| delta_left = timestamp.time -
|     ticks_left.currentTicks * ticks_left.tickRate / 1000
|
| delta_right = timestamp.time -
|     ticks_right.currentTicks * ticks_right.tickRate / 1000
```

Figure 11: Verification of Synchronization Token

```
| compositeHash = hash_init()
| for value in Composite.values:
|     hash_update(compositeHash, value)
| compositeHash = hash_finish(compositeHash)
|
| certInfo = reconstruct_static(TPM-CERTIFY-INFO)
|
| assert(Composite.bitmask == ExpectedPCRBitmask)
| assert(certInfo.pcrinfo.PCRSelection == Composite.bitmask)
| assert(certInfo.pcrinfo.digestAtRelease == compositeHash)
| assert(certInfo.pubkeyDigest == hash(restrictedKey_Pub))
|
| verifySig(AIK_pub, dummyNonce || certInfo)
```

Figure 12: Verification of Restriction Info

```
| for event in Measurement-Log:
|     if event.pcr not in ExpectedPCRBitmask:
|         continue
|     if event.type == BIOS:
|         assert_whitelist-bios(event.pcr, event.template-hash)
|     if event.type == ima:
|         assert(event.pcr == 10)
|         assert_whitelist(event.pathname, event.filedata-hash)
|         assert(event.template-hash ==
|                hash(event.pathname || event.filedata-hash))
|     if event.type == ima-ng:
|         assert(event.pcr == 10)
|         assert_whitelist-ng(event.pathname, event.filedata-hash)
|         assert(event.template-hash ==
|                hash(event.pathname || event.filedata-hash))
|
|     virtPCR[event.pcr] = hash_extend(virtPCR[event.pcr],
|                                      event.template-hash)
|
| for pcr in ExpectedPCRBitmask:
|     assert(virtPCR[pcr] == Composite.values[i++]
```

Figure 13: Verification of Measurement Log

```
| ts = Verifytoken
|
| /* Reconstruct ts's omitted values; Alternatively assert == */
| ts.currentTicks.tickRate = ts_left.currentTicks.tickRate
| ts.currentTicks.tickNonce = ts_left.currentTicks.tickNonce
|
| verifySig(restrictedKey_pub, dummyNonce || dummyDigest || ts)
|
| ticks = ts.currentTicks
|
| time_left = delta_right + ticks.currentTicks * ticks.tickRate / 1000
| time_right = delta_left + ticks.currentTicks * ticks.tickRate / 1000
|
| [time_left, time_right]
```

Figure 14: Verification of Attestation Token

D.3. IE Generation Procedures for TPM 2.0

The pseudo code below includes general operations that are conducted as specific TPM commands:

- hash() : description TBD
- sig() : description TBD
- X.509-Certificate() : description TBD

These represent the output structure of that command in the form of a byte string value.

D.3.1. AIK and AIK Certificate

Attestations are based upon a cryptographic signature performed by the TPM using a so-called Attestation Identity Key (AIK). An AIK has the properties that it cannot be exported from a TPM and is used for attestations. Trust in the AIK is established by an X.509 Certificate emitted by a Certificate Authority. The AIK certificate is either provided directly or via a so-called PrivacyCA [AIK-Enrollment].

This element consists of the AIK certificate that includes the AIK's public key used during verification as well as the certificate chain up to the Root CA for validation of the AIK certificate itself.

```
TUDA-Cert = [AIK-Cert, TSA-Cert]; maybe split into two for SNMP
AIK-Certificate = X.509-Certificate(AIK-Key,Restricted-Flag)
TSA-Certificate = X.509-Certificate(TSA-Key, TSA-Flag)
```

Figure 15: TUDA-Cert element for TPM 2.0

D.3.2. Synchronization Token

The synchronization token uses a different TPM command, TPM2 GetTime() instead of TPM TickStampBlob(). The TPM2 GetTime() command contains the clock and time information of the TPM. The clock information is the equivalent of TUDA v1's tickSession information.

```
TUDA-SyncToken = [
  left_GetTime = sig(AIK-Key,
                     TimeInfo = [
                       time,
                       resetCount,
                       restartCount
                     ]
                    ),
  middle_TimeStamp = sig(TSA-Key,
                         hash(left_TickStampBlob),
                         UTC-localtime
                        ),
  right_TickStampBlob = sig(AIK-Key,
                            hash(middle_TimeStamp),
                            TimeInfo = [
                              time,
                              resetCount,
                              restartCount
                            ]
                           )
]
```

Figure 16: TUDA-Sync element for TPM 2.0

D.3.3. Measurement Log

The creation procedure is identical to Appendix D.2.4.

```
Measurement-Log = [
  * [ EventName,
      PCR-Num,
      Event-Hash ]
]
```

Figure 17: TUDA-Log element for TPM 2.0

D.3.4. Explicit time-based Attestation

The TUDA attestation token consists of the result of TPM2_Quote() or a set of TPM2_PCR_READ followed by a TPM2_GetSessionAuditDigest. It proves that -- at a certain point-in-time with respect to the TPM's internal clock -- a certain configuration of PCRs was present, as denoted in the keys restriction information.

```
TUDA-AttestationToken = TUDA-AttestationToken_quote / TUDA-
AttestationToken_audit

TUDA-AttestationToken_quote = sig(AIK-Key,
                                  TimeInfo = [
                                    time,
                                    resetCount,
                                    restartCount
                                  ],
                                  PCR-Selection = [ * PCR],
                                  PCR-Digest := PCRDigest
                                 )

TUDA-AttestationToken_audit = sig(AIK-key,
                                  TimeInfo = [
                                    time,
                                    resetCount,
                                    restartCount
                                  ],
                                  Session-Digest := PCRDigest
                                 )
```

Figure 18: TUDA-Attest element for TPM 2.0

D.3.5. Sync Proof

In order to proof to the Verifier that the TPM's clock was not 'fast-forwarded' the result of a TPM2_GetTime() is sent after the TUDA-AttestationToken.

```
TUDA-SyncProof = sig(AIK-Key,
                     TimeInfo = [
                       time,
                       resetCount,
                       restartCount
                     ]
                    ),
```

Figure 19: TUDA-Proof element for TPM 2.0

Acknowledgements

Authors' Addresses

Andreas Fuchs
Fraunhofer Institute for Secure Information Technology
Rheinstrasse 75
Darmstadt 64295
Germany

Email: andreas.fuchs@sit.fraunhofer.de

Henk Birkholz
Fraunhofer Institute for Secure Information Technology
Rheinstrasse 75
Darmstadt 64295
Germany

Email: henk.birkholz@sit.fraunhofer.de

Ira E McDonald
High North Inc
PO Box 221
Grand Marais 49839
US

Email: blueroofmusic@gmail.com

Carsten Bormann
Universitaet Bremen TZI
Bibliothekstr. 1
Bremen D-28359
Germany

Phone: +49-421-218-63921
Email: cabo@tzi.org