Formal Specification and Verification of Architecturally-defined Attestation Mechanisms in Arm CCA and Intel TDX

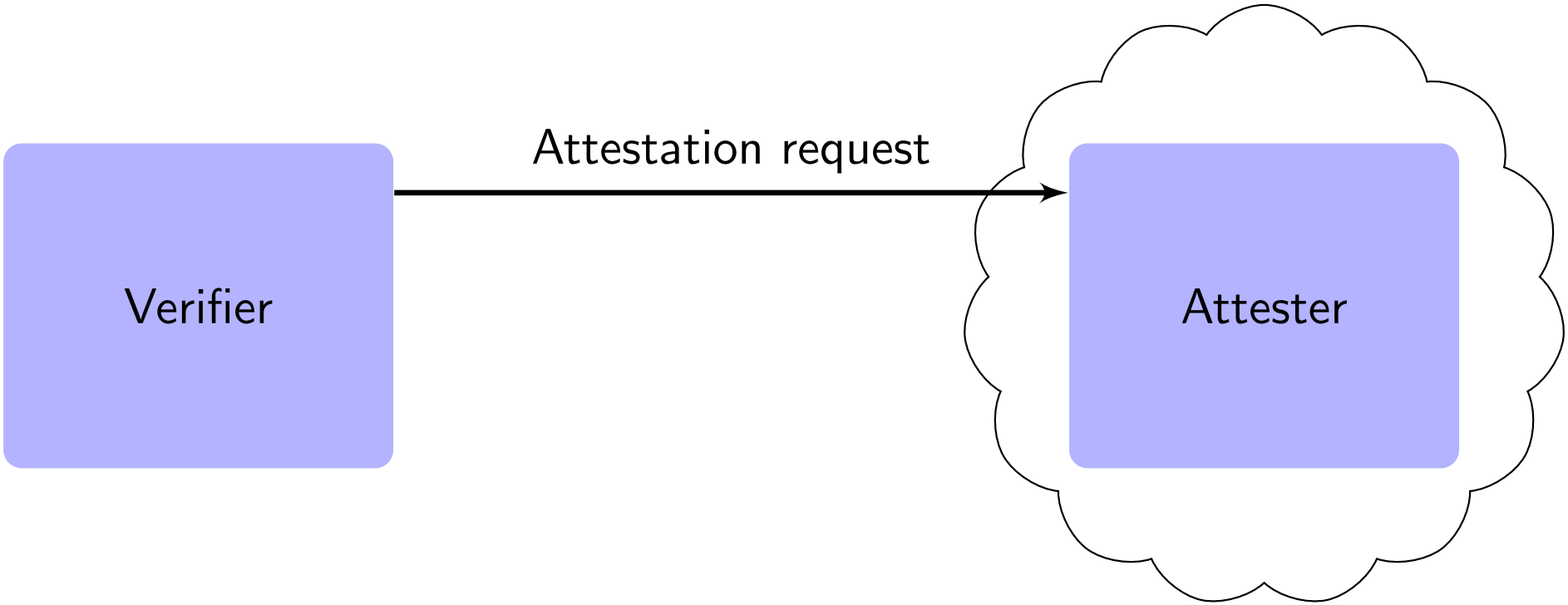
Muhammad Usama Sardar

TU Dresden

April 3, 2024

Agenda

Attestation in Confidential Computing[1] (Simplified)



[1] Sardar and Fetzer, "Confidential computing and related technologies: a critical review", 2023.

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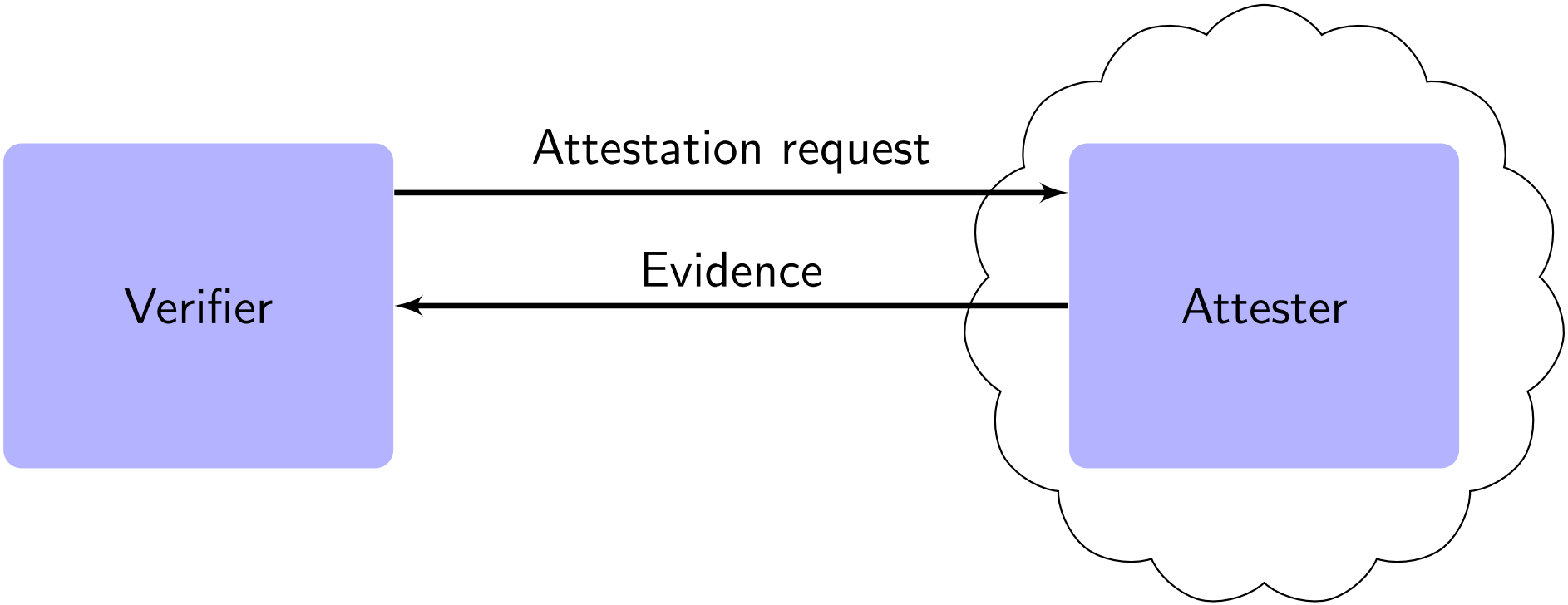

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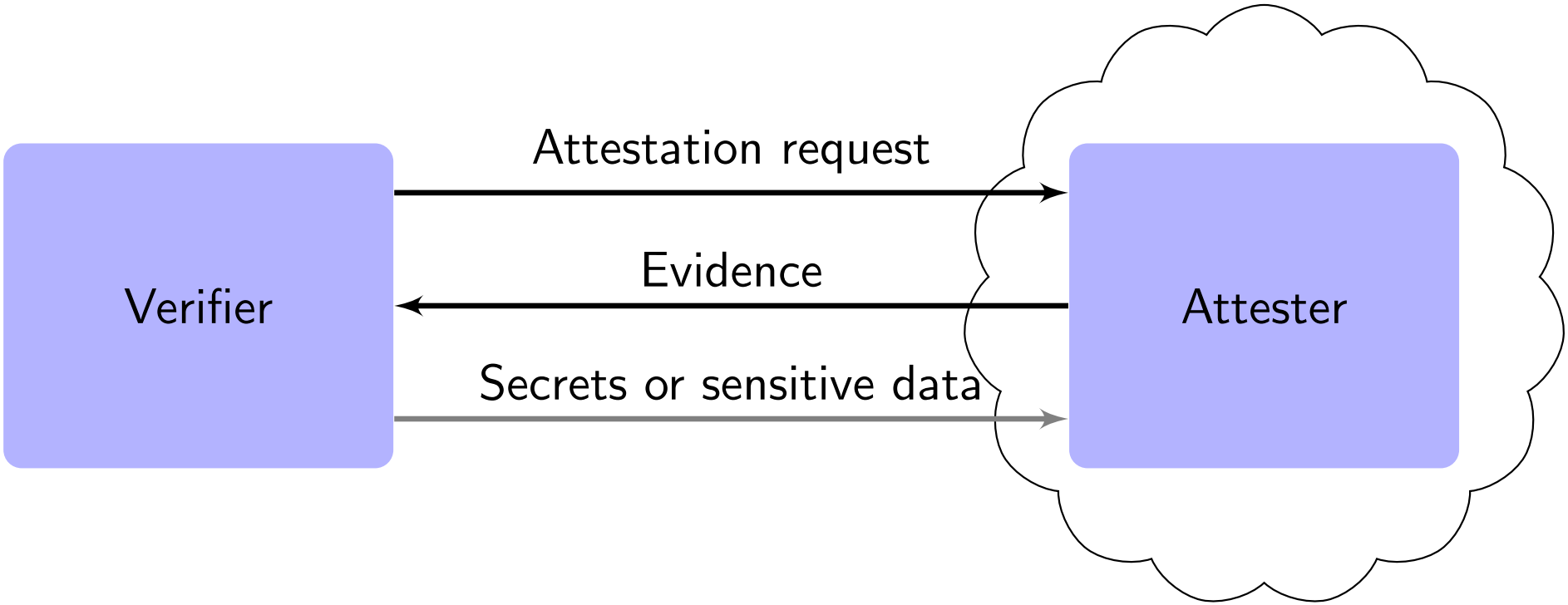


[1] Sardar and Fetzer, "Confidential computing and related technologies: a critical review", 2023.

Problem: ad-hoc and unverified designs[2]

sgaxe.com

Signing Your Own Quotes

We understand that remote attestion can be very tricky to pass. However, since we already done all the hard work of getting genuine attestation keys, we decided to help you out by developing a Twitter bot that passes SGX attestation for you. Our bot provides Attestation as a Service (AaaS), which allows you to get your own quotes signed with the keys we extracted using SGAxe. This way you can pass attestation without even owning an SGX machine. If you want to make use of our service, you can send a tweet to our bot @SGAxe_AaaS. If you'll tweet it, we'll sign it!

@SGAxe_AaaS

[2] `www.sgaxe.com`

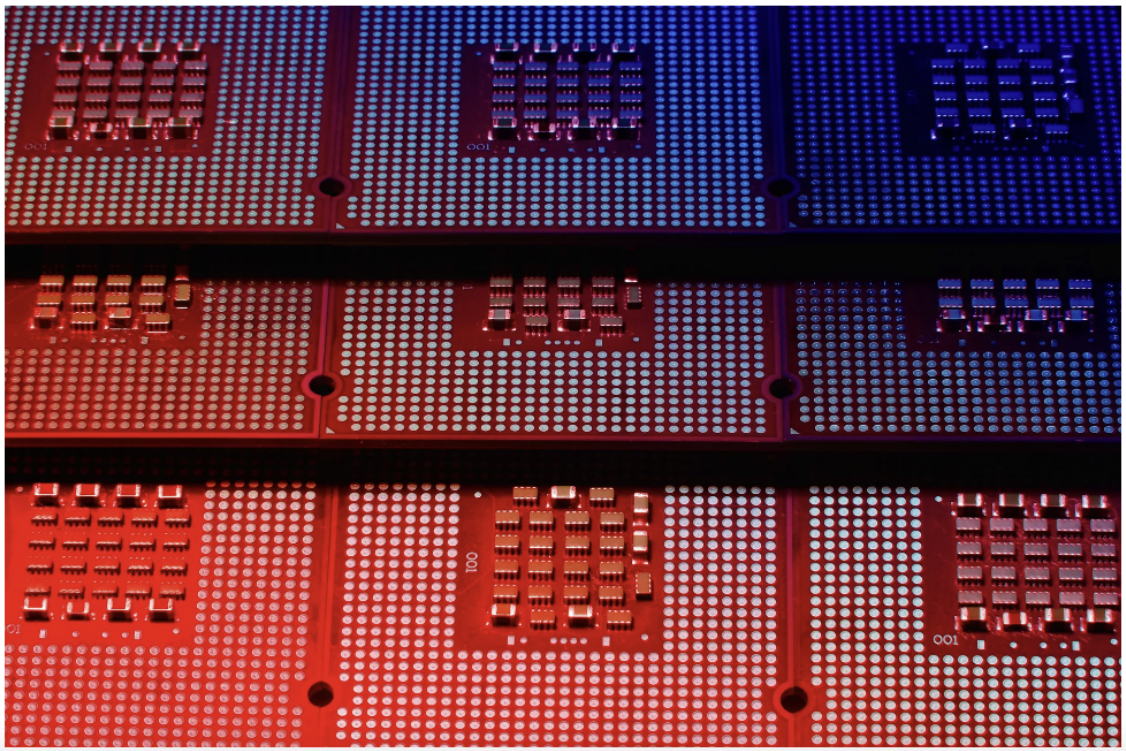
Next-generation TDX[3]

WIRED BACKCHANNEL BUSINESS CULTURE GEAR IDEAS SCIENCE SECURITY

LILY HAY NEWMAN SECURITY APR 24, 2023 1:12 PM

Intel Let Google Cloud Hack Its New Secure Chips and Found 10 Bugs

To protect its Confidential Computing cloud infrastructure and gain critical insights, Google leans on its relationships with chipmakers.



PHOTOGRAPH: GETTY IMAGES

[3]Wired, *Intel Let Google Cloud Hack Its New Secure Chips and Found 10 Bugs*, 2023.

Related Work

- Intel SGX EPID[4]

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- Intel SGX and AMD SEV[7]

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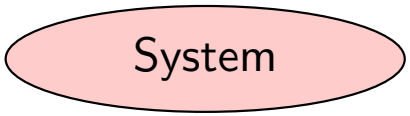

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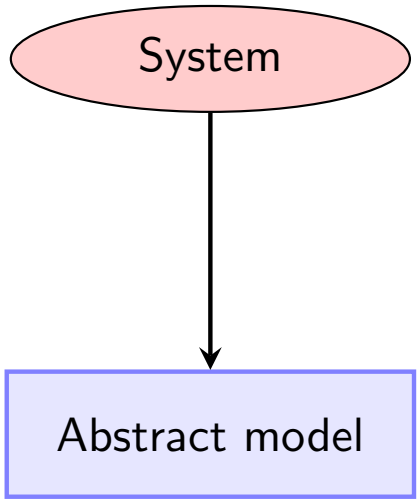

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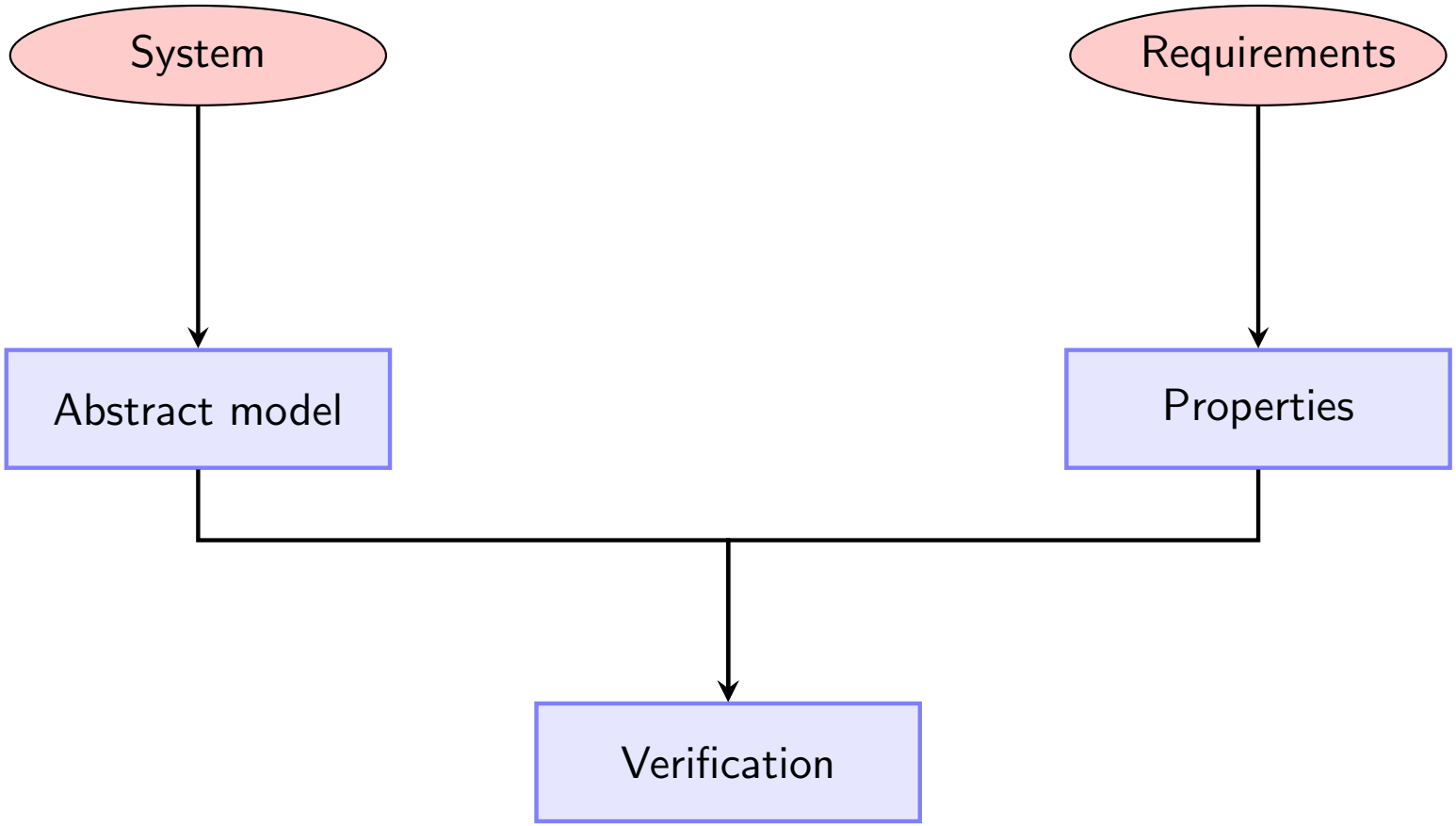


Agenda

2. Approach
   - Model
   - Properties

Challenge 1: Incomplete specs[8]

Wan_Intel
Moderator
09-18-2023 • 07:57 PM • 656Aufrufe

Hello UsamaS,

I've checked with the relevant team.

The "internal specs" that we've mentioned in the thread above are part of an internal document used by our developers and it would not be relevant to customers. Sorry for the inconvenience and thank you for your support.

Regards,

Wan

[8] https://community.intel.com/t5/Intel-Software-Guard-Extensions/Missing-specification-documents-for-TDX/m-p/1527218

Challenge 2: Vague and outdated specs[9]

Peh_Intel 09-14-2023 • 06:04 PM • 397Aufrufe
Moderator

Hi UsamaS,

Thanks for your patience. I just received the updates as follow.

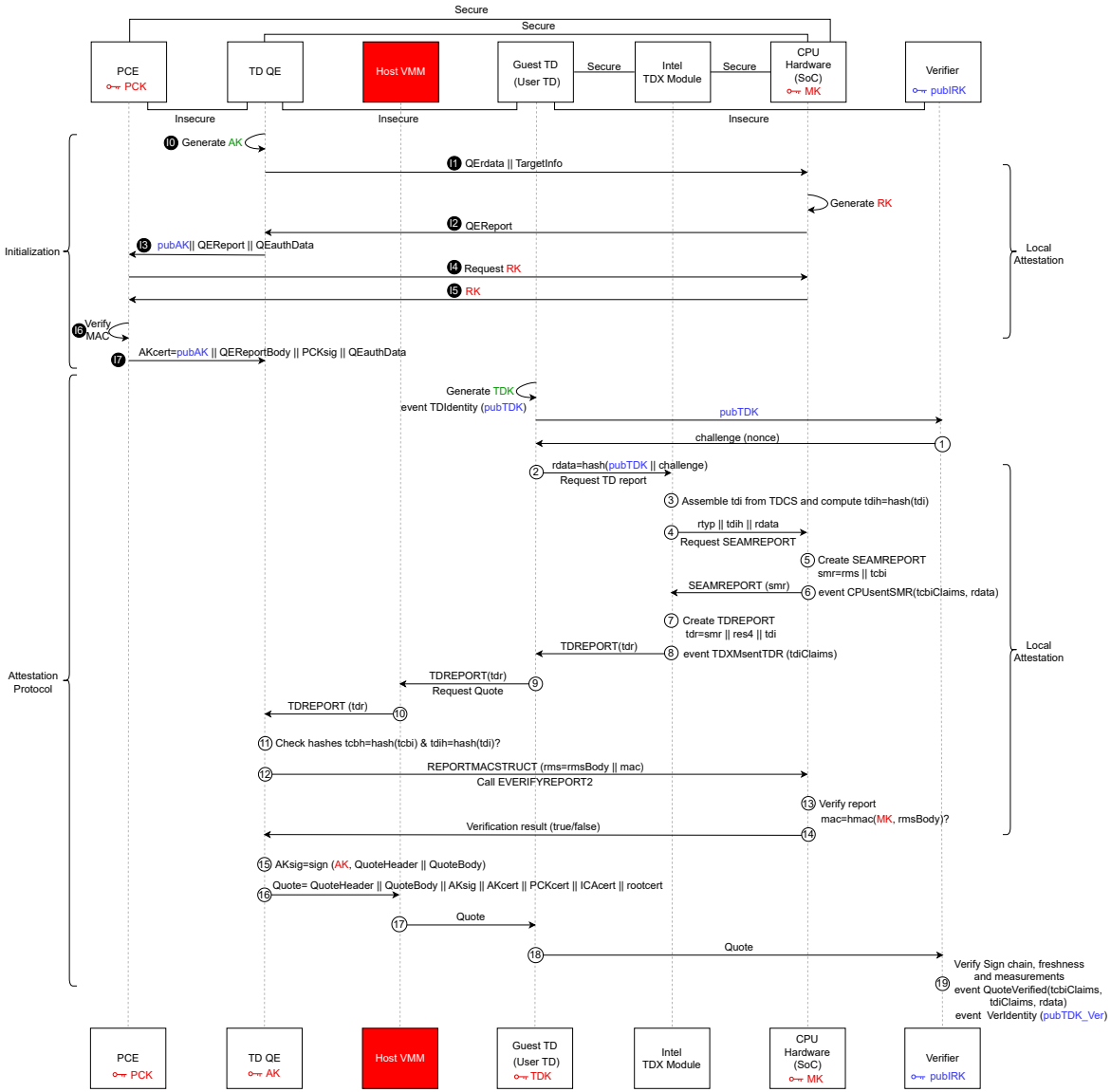
This index 1 SVN is the TDX Module major version. Originally, there was only 1 TDX 1.0 module, so the SVN had to match. Now that we have TDX 1.5 coming, it has a new major version, so the logic has to change, and those steps will also. The API doc will be updated soon to reflect this.

Regards,

Peh

[9] `https://community.intel.com/t5/Intel-Software-Guard-Extensions/index-1-in-tdxtcbcomponents/m-p/1520194`

TDX Model with Initialization Phase (PCE)



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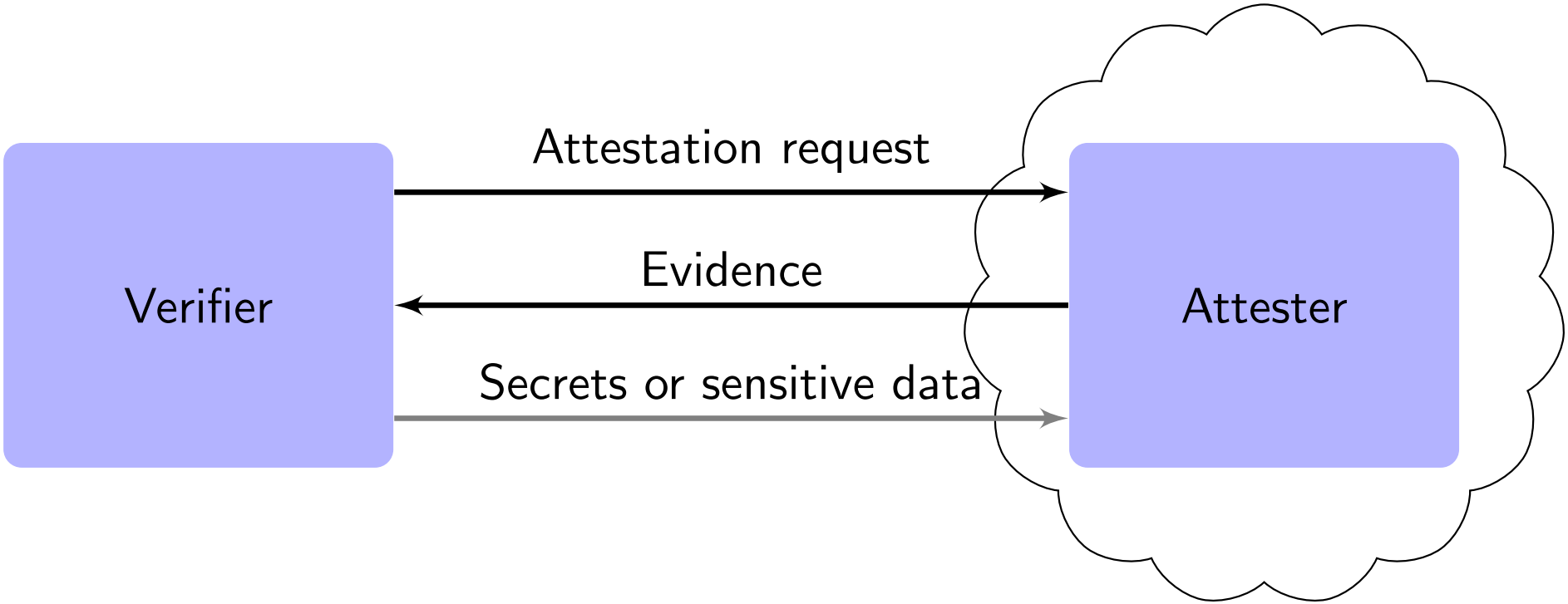
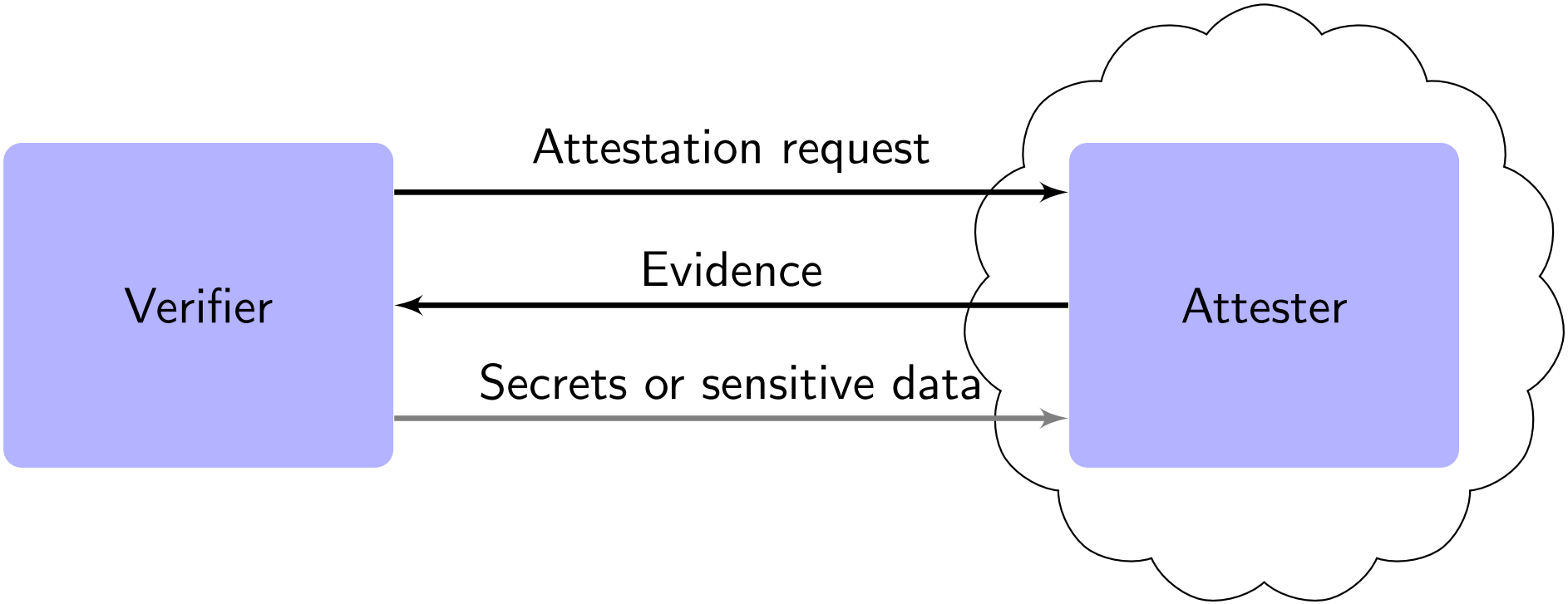


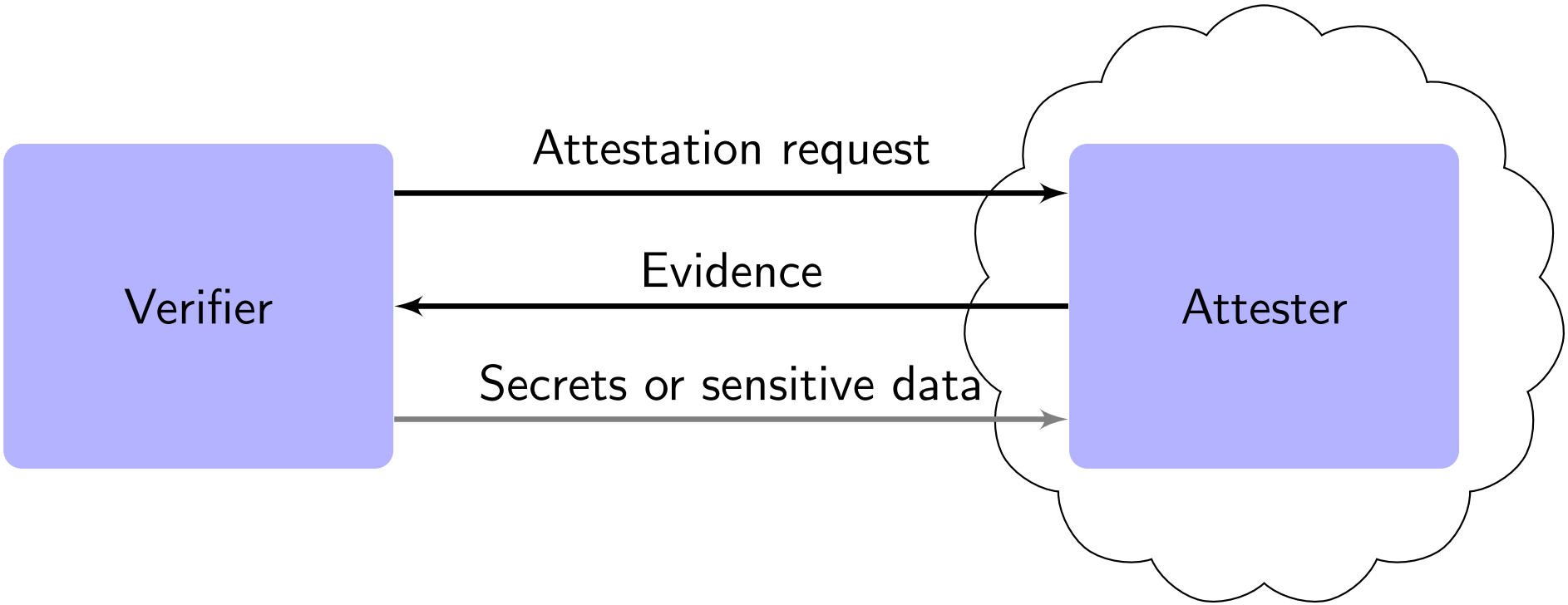
- Sanity checks

Properties



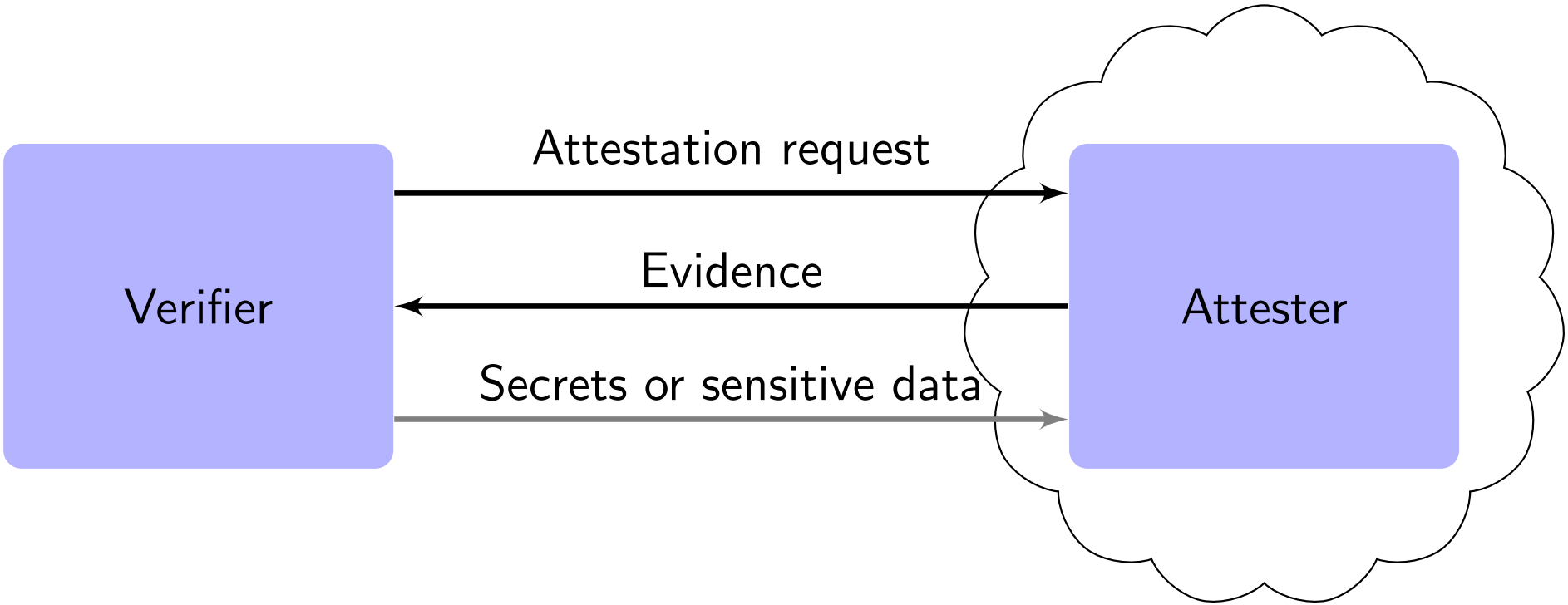
- Sanity checks
- Integrity of Evidence

Properties



- Sanity checks
- Integrity of Evidence
- Freshness of Evidence

Properties



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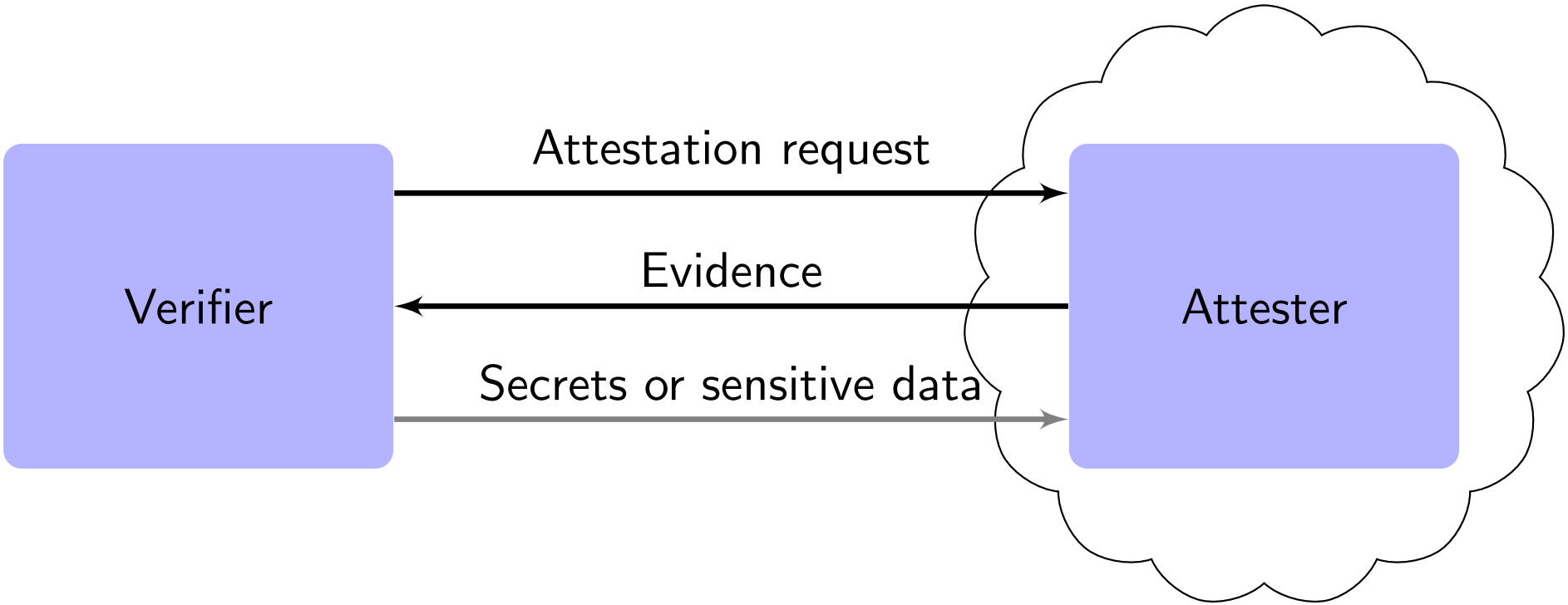


- Sanity checks
- Integrity of Evidence
- Freshness of Evidence
- Confidentiality/Secrecy of attestation-related keys
- Attester Authentication

Agenda

TCB Claimed by Intel[10]

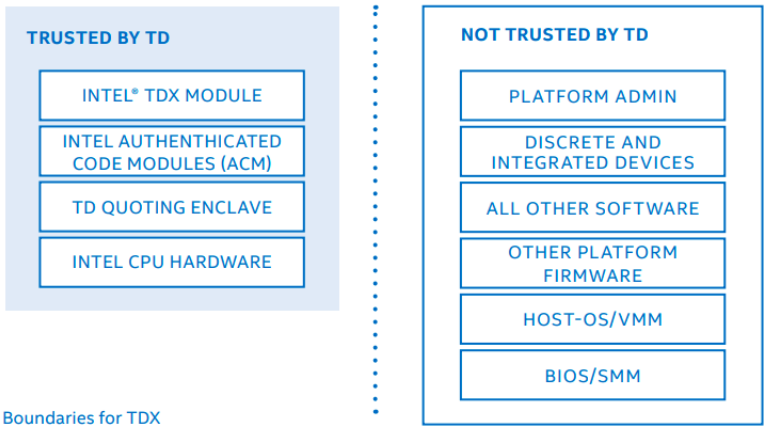
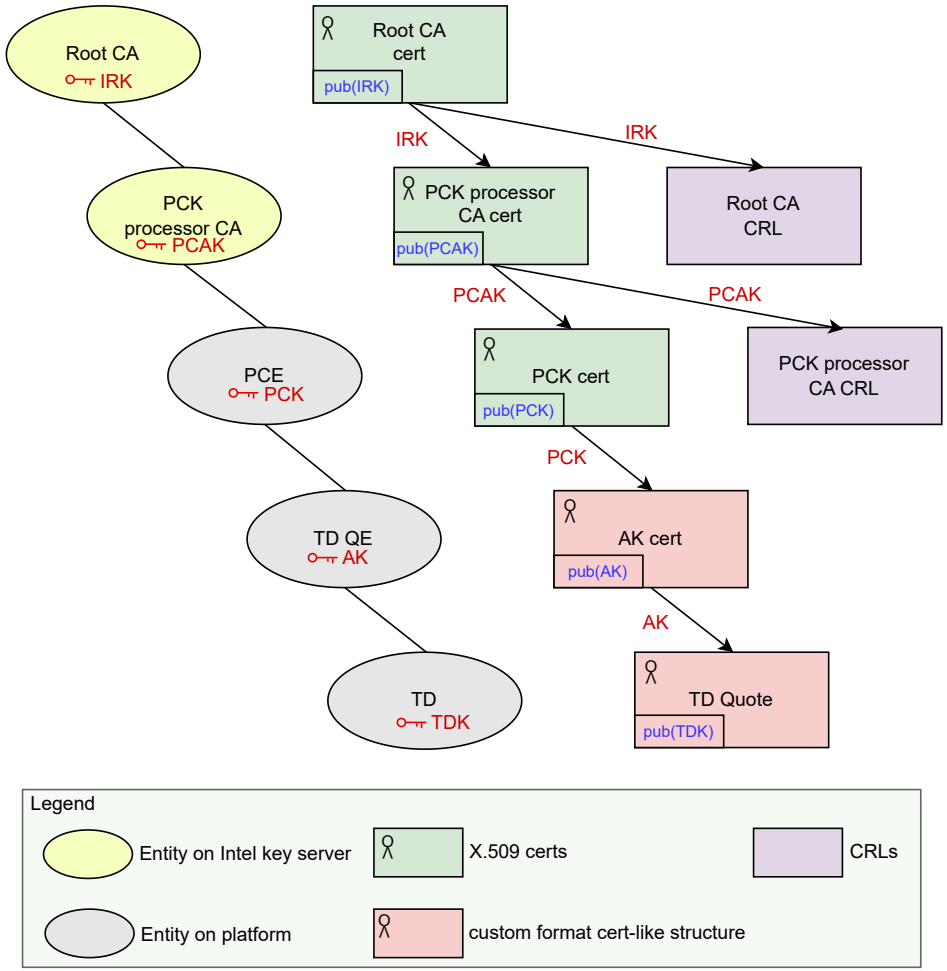


Figure 5.1. Trust Boundaries for TDX



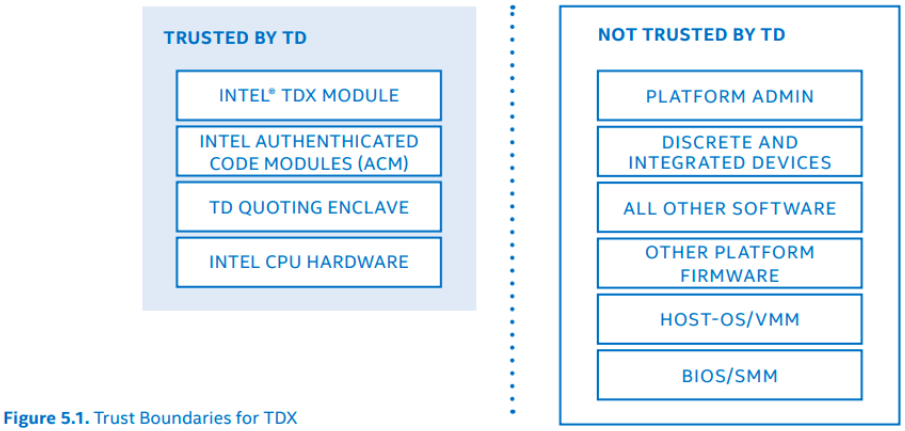
[10] Intel, *Intel ® Trust Domain Extensions*, 2021.

Verification Summary

	Integrity	Freshness	Confidentiality	Authentication
Intel's claimed TCB	×	×	×	×
Our proposed TCB	✓	✓	✓	×

```
------------------------------------------------------------
Verification summary:

Query not event(AKverified(pubAK_1)) is false.

Query not event(CPUsentSMR(tcbiClaims_1,rdata_1)) is false.

Query not event(TDXMsentTDR(tdiClaims_1)) is false.

Query not event(QuoteVerified(tcbiClaims_1,tdiClaims_1,rdata_1)) is false.

Query not (event(TDidentity(pubTDK_1)) && event(VerIdentity(pubTDK_Ver_1))) is false.

Query event(AKverified(pubAK_1)) ==> event(AKsent(pubAK_1)) is true.

Query event(QuoteVerified(tcbiClaims_1,tdiClaims_1,rdata_1)) ==> event(CPUsentSMR(tcbiClaims_1,rdata_1)) is false.

Query event(QuoteVerified(tcbiClaims_1,tdiClaims_1,rdata_1)) ==> event(TDXMsentTDR(tdiClaims_1)) is false.

Query inj-event(QuoteVerified(tcbiClaims_1,tdiClaims_1,rdata_1)) ==> inj-event(CPUsentSMR(tcbiClaims_1,rdata_1)) is false.

Query inj-event(QuoteVerified(tcbiClaims_1,tdiClaims_1,rdata_1)) ==> inj-event(TDXMsentTDR(tdiClaims_1)) is false.

Query secret PCK_1,PCK is false.

Query secret PCAK is true.

Query secret AK_2,AK_1,AK is true.

Query secret MK_1,MK is true.

Query event(AKverified(pubAK_PCE_1)) && event(AKsent(pubAK_1)) ==> pubAK_PCE_1 = pubAK_1 is true.

Query event(VerIdentity(pubTDK_Ver_1)) && event(TDidentity(pubTDK_1)) ==> pubTDK_1 = pubTDK_Ver_1 is false.

------------------------------------------------------------


real    0m55,648s
user    0m55,432s
sys     0m0,132s
```

Reported to Intel[12] and Fixed[13]



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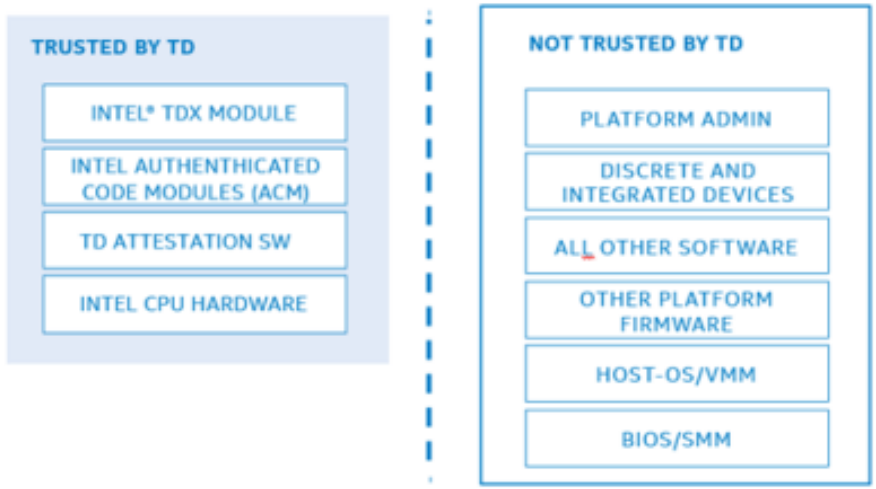

Figure 1 Trust Boundaries for TDX

Figure: Updated

[11] Sardar, *Full transparency of Intel TDX Specifications*, 2023.

[12] Intel, *Intel ® Trust Domain Extensions*, 2021.

[13] Intel, *Intel ® Trust Domain Extensions*, 2023.

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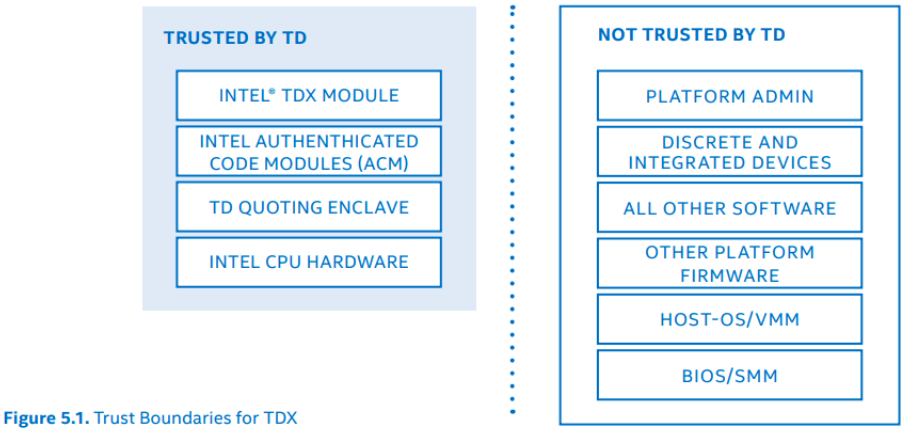

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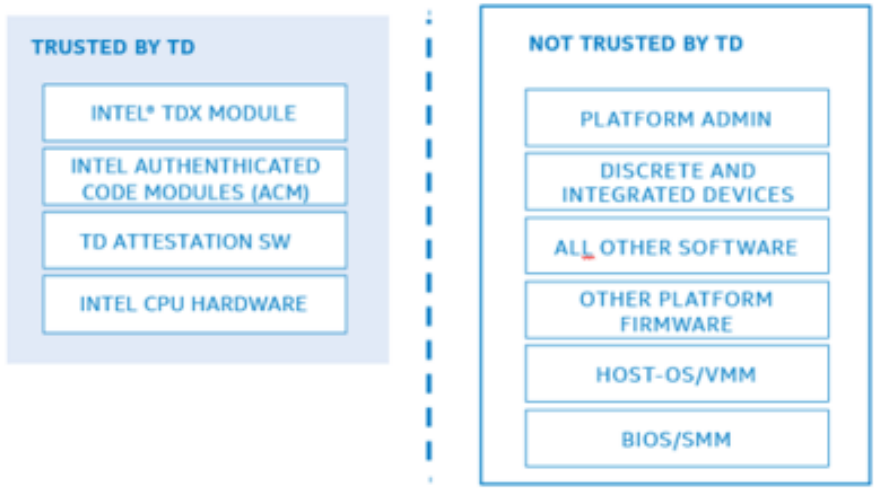

Figure: Updated

- Warning: on same URL replacing the old white paper: Reported to Intel privately and publicly[11]

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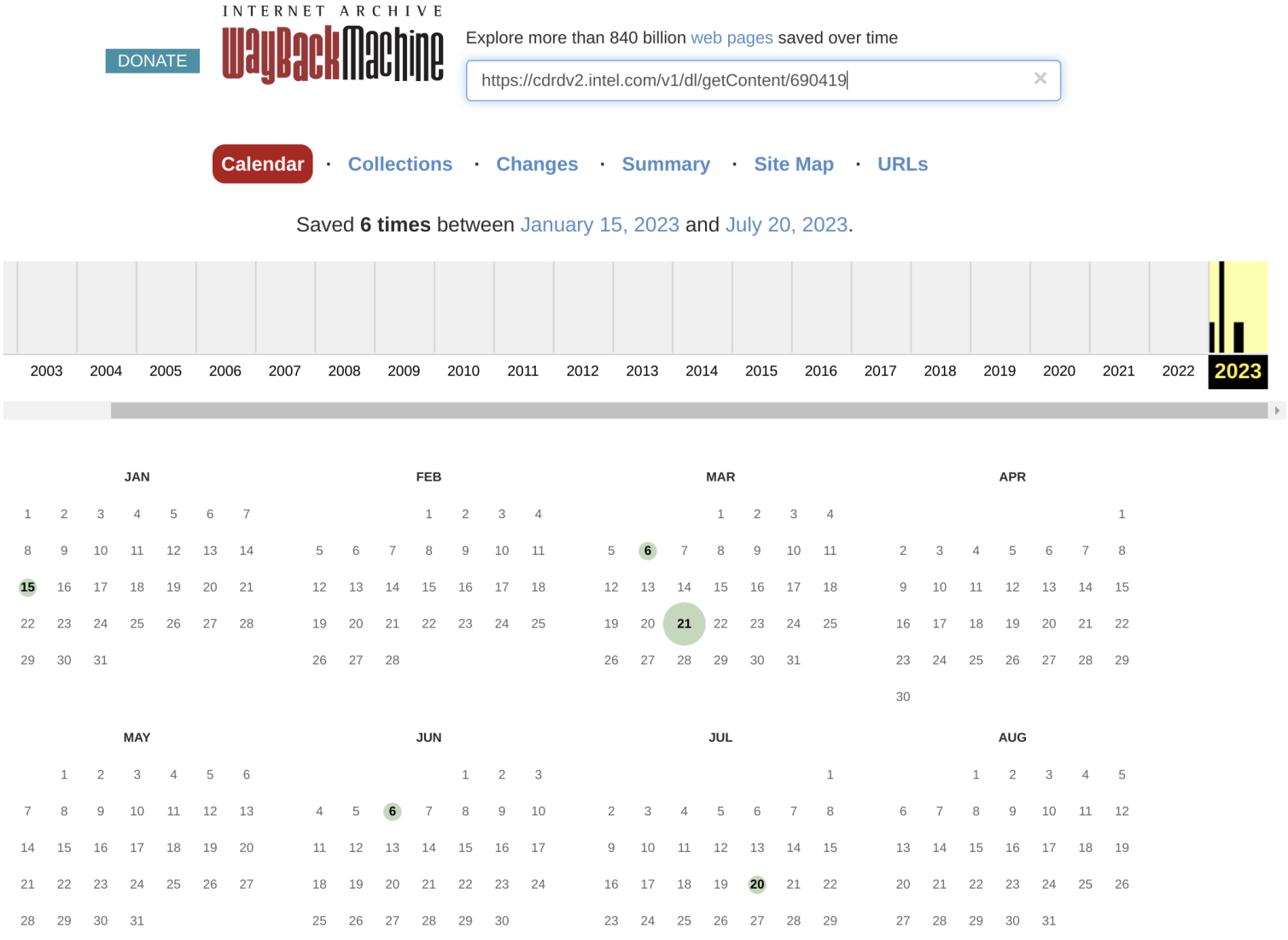
Evidence[14]



[14] https://web.archive.org/web/20230000000000*/https://cdrdv2.intel.com/v1/dl/getContent/690419

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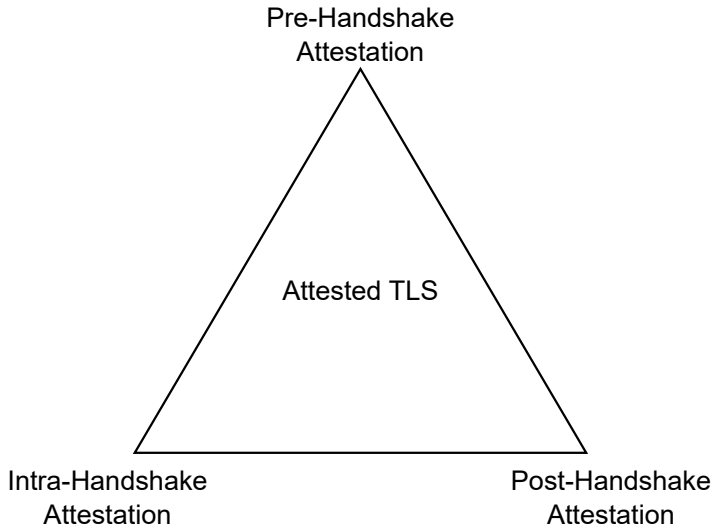
Attested TLS



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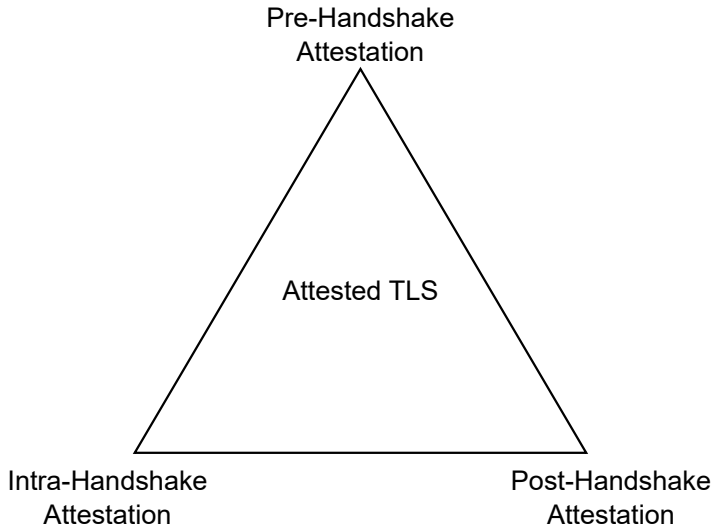

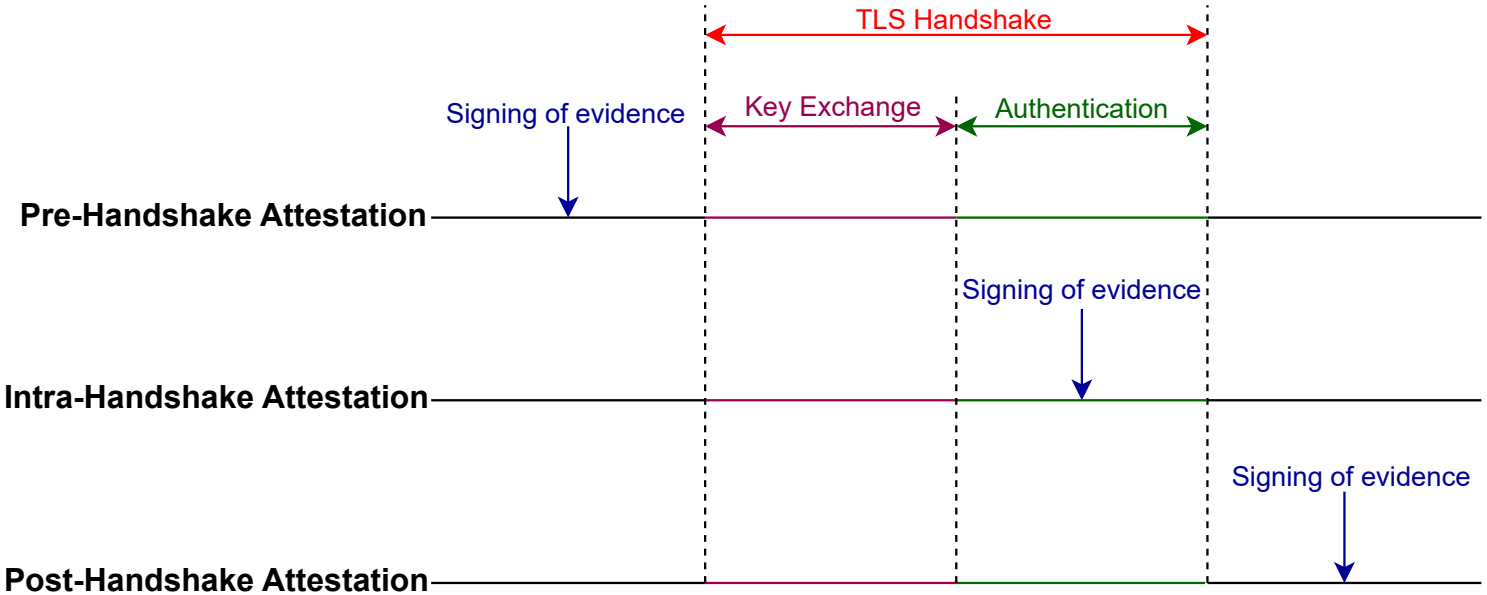

"Rollercoaster"

- Incomplete and outdated specs for RA-TLS[15]

[15] Knauth et al., *Integrating Remote Attestation with Transport Layer Security*, 2018.

[16] `https://github.com/Inria-Prosecco/reftls/tree/master/pv`

[17] `https://mailarchive.ietf.org/arch/msg/tls/-nFk9Eu7n-YFsFfGUe9X4JnrxX8/`

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- A simple extension made the artifacts running for 1 month on high-end server (icelake)
  - Submitted to ProVerif developers for analysis

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  - Fix: Used implementation and community input for formal model
- Very few comments in Inria's TLS formal model[16]
  - Literally no comments at all in main processes (such as Client12, Server12, Client13, Server13, appData, channelBindingQuery and secrecyQuery)!
- Incomplete validation of draft 20 artifacts[17]
  - Fix: Designed an automated validation framework for key schedule
- A simple extension made the artifacts running for 1 month on high-end server (icelake)
  - Submitted to ProVerif developers for analysis
  - Fix: Formal model from scratch

[15] Knauth et al., *Integrating Remote Attestation with Transport Layer Security*, 2018.

[16] `https://github.com/Inria-Prosecco/reftls/tree/master/pv`

[17] `https://mailarchive.ietf.org/arch/msg/tls/-nFk9Eu7n-YFsFfGUe9X4JnrxX8/`

Community input

- Paper authors[18]
  - Bruno Blanchet
  - Karthikeyan Bhargavan
  - Nadim Kobeissi
- LURK[19] authors
- IETF TLS WG[20]
- IRTF UFMRG chairs
- CCC attestation SIG[21]
- ...
- IETF 119 Hackathon[22]
- IRTF Crypto Forum RG @ IETF 119[23]

[18] Bhargavan, Blanchet, and Kobeissi, "Verified Models and Reference Implementations for the TLS 1.3 Standard Candidate", 2017.

[19] https://github.com/lurk-t/proverif

[20] https://mailarchive.ietf.org/arch/msg/tls/ZGmyHwTYh2iPwPrirj_rkSTYhDo/

[21] https://github.com/CCC-Attestation/meetings/blob/main/materials/MuhammadUsamaSardar_Formal_RA-TLS.pdf

[22] https://wiki.ietf.org/meeting/119/hackathon

[23] https://datatracker.ietf.org/meeting/119/materials/slides-119-cfrg-formal-analysis-of-ra-tls-00

Outline

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- Formal proof of insecurity of Intel's claimed TCB
- Arch-def attestation does not provide strong authentication property (see paper)
- Validation of formal model is crucial!
- Open question: security of attested TLS

Key References I

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Call to Action

- Bring your expertise: https://github.com/CCC-Attestation/formal-spec-TEE
- Additional information: link here[24]

[24] Sardar, Fossati, et al., *Formal Specification and Verification of Architecturally-defined Attestation Mechanisms in Arm CCA and Intel TDX*, 2023.