A Rollercoaster Ride on the Formal Analysis of Attested TLS

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[4]Linaro, Lausanne, Switzerland

March 28, 2024

Agenda

1. TLS
2. Attestation (RA)
3. Attested TLS (RA+TLS)
4. Contributions
5. Approach and Tool
6. Validation of TLS 1.3
7. Formal Analysis of Attested TLS
8. Summary

Data-in-transit: Transport Protocols

- TLS[1]: world's most-used cryptographic protocol

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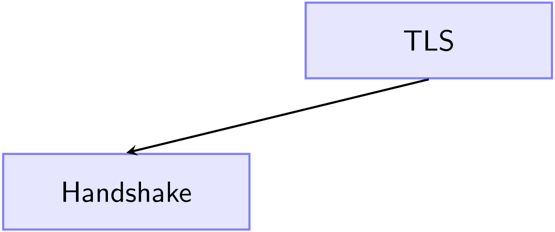

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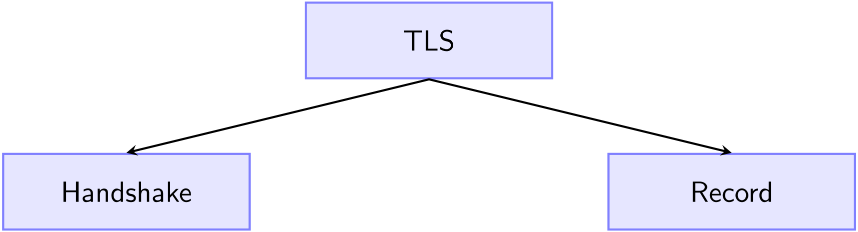

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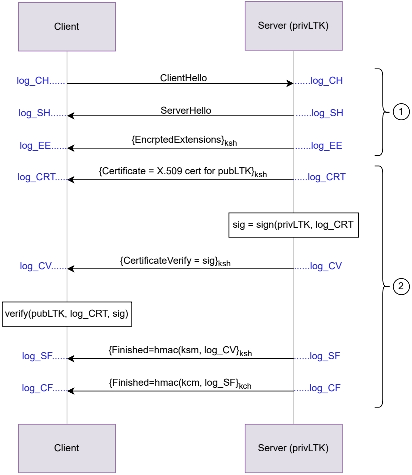
TLS Handshake Protocol

- Most complex part of TLS
  1. Unauthenticated key exchange (and parameter negotiation)
  2. Authentication (inc. key confirmation)



Problem in TLS

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- No validation of security state of endpoint software and platform
  - Need a more comprehensive set of security metrics in some use cases, e.g., CC
- Very complex: at least 15 different exploits
  - Is all complexity (e.g., of key schedule) justified?

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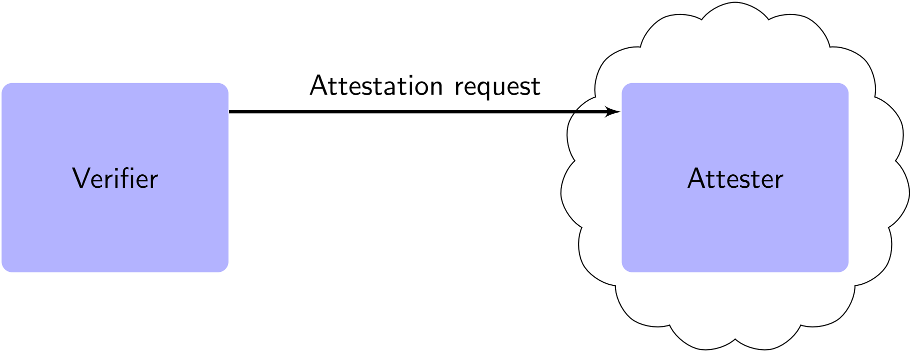
Architecturally-defined Attestation



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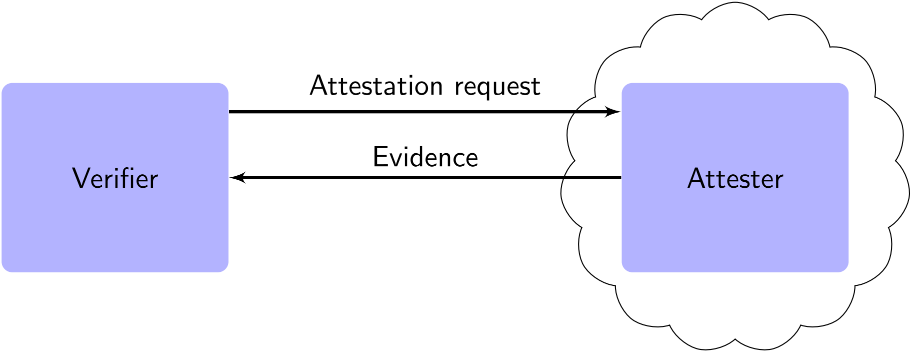

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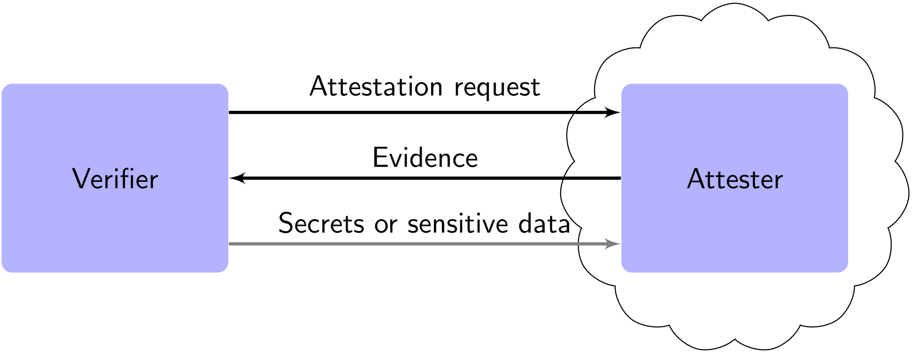

Data-in-use: Architecturally-defined attestation[2]

- Intel TDX

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

- Arm CCA

Attester	Integrity	Freshness	Confidentiality	Authentication
Platform	✓	×	✓	×
Realm	✓	✓	✓	×

- Problem 1: No server authentication (e.g., misconfiguration)
- Problem 2: No standard way of implementation

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

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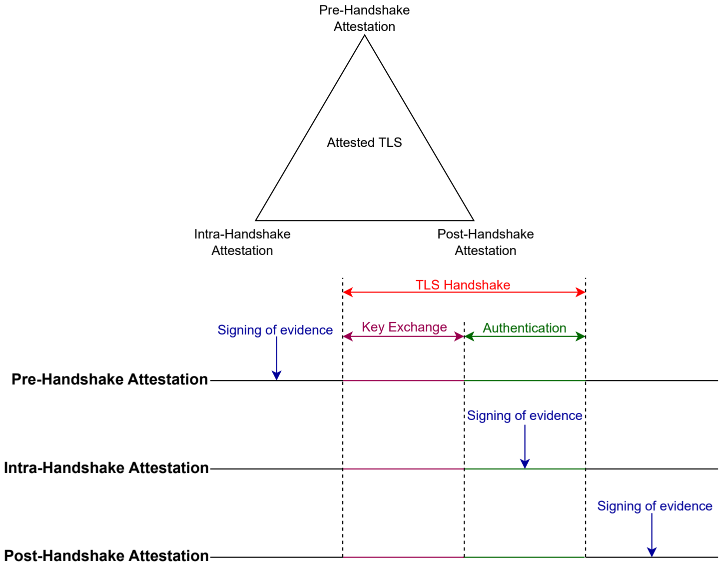
Data-in-transit + Data-in-use



Intel's RA-TLS[3]

- Widely used protocol, e.g., in Gramine, RATS-TLS, Open Enclave Attested TLS, and SGX SDK Attested TLS

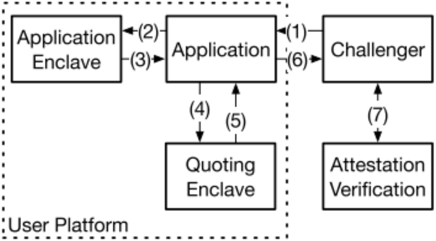


Figure 1: Remote Attestation Example. The challenger is off-platform with respect to the attester.

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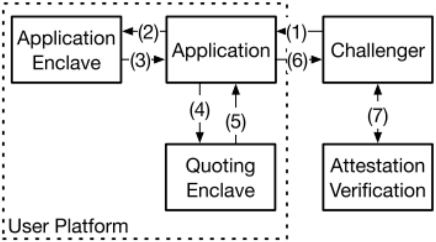

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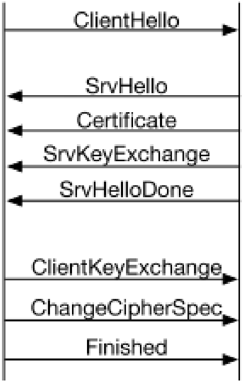

Figure 2: TLS 1.2 Handshake Messages.

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Contributions

- Validation of formal model[4] of TLS 1.3 Key Schedule, revealing 3 major issues

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- Validation of formal model[4] of TLS 1.3 Key Schedule, revealing 3 major issues
- First formal analysis of attested TLS for TEEs

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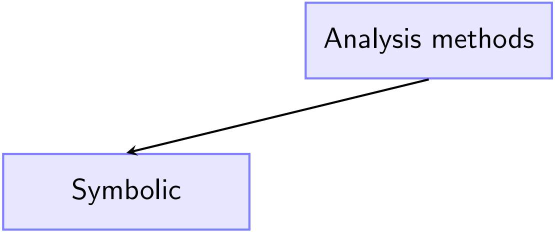
Analysis Approach[6] and Tool



[5] Blanchet, Cheval, and Cortier, "ProVerif with lemmas, induction, fast subsumption, and much more", 2022.

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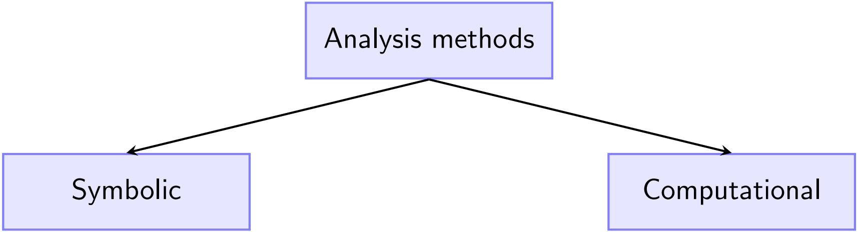

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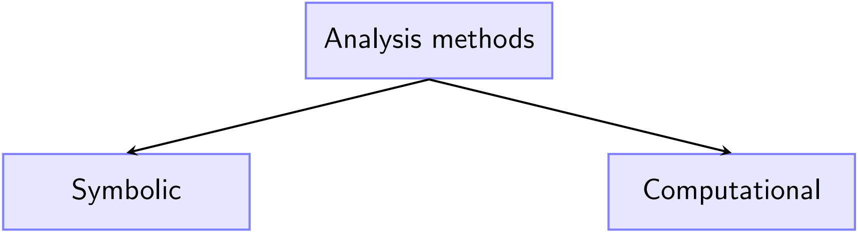

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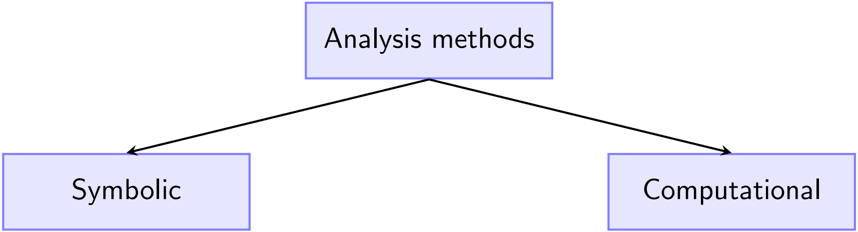

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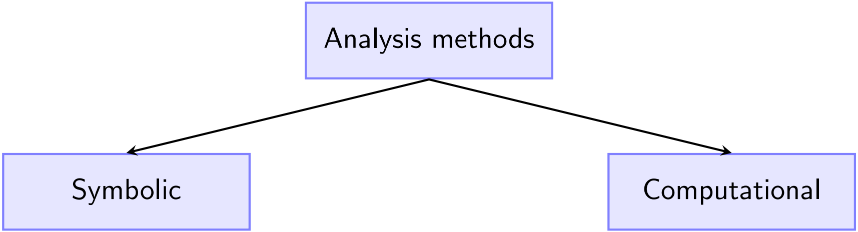

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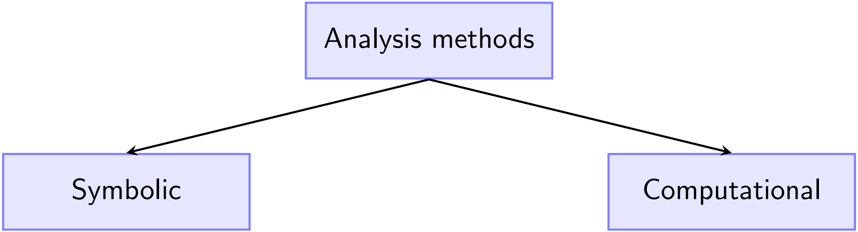

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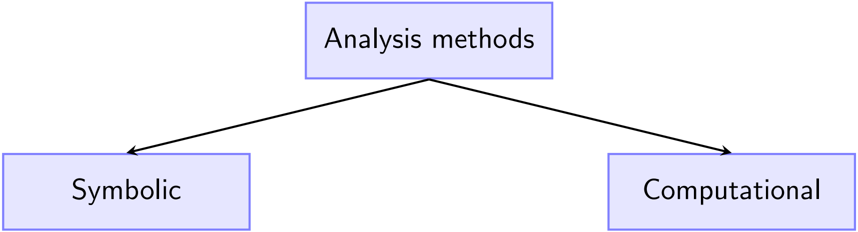

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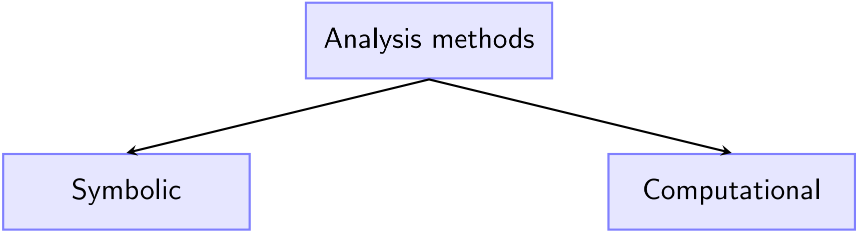

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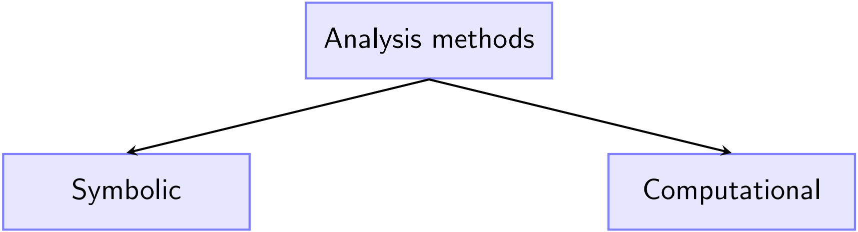

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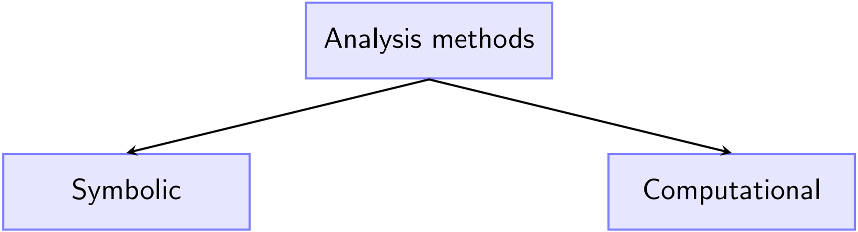

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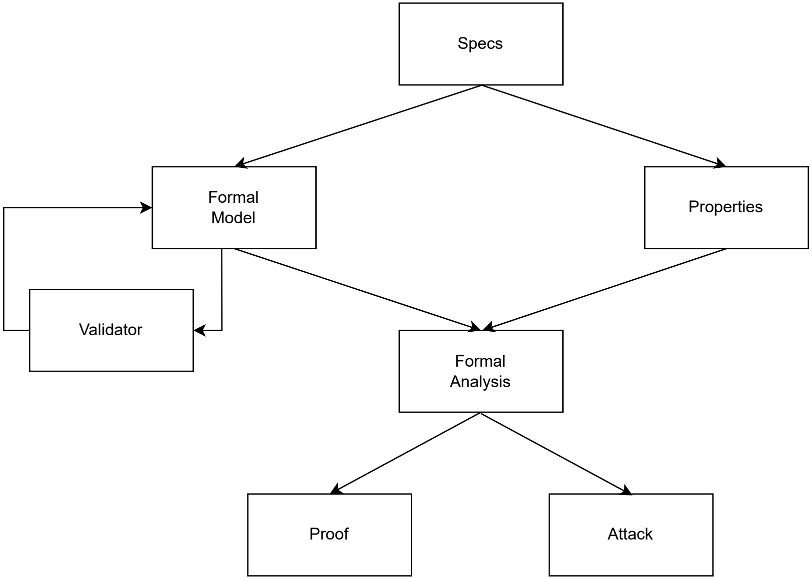
Approach - Simplified



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  - Fix: Formal model from scratch

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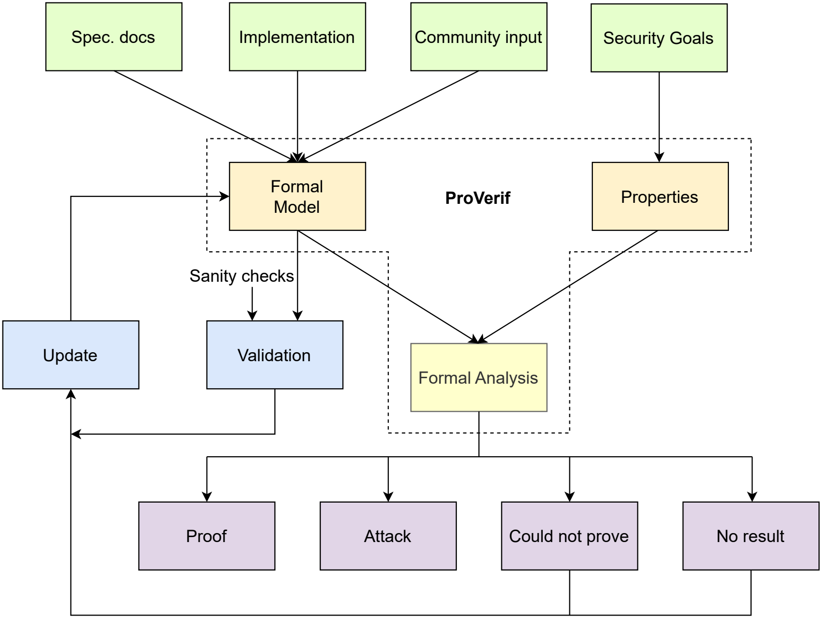
Approach



Spec. docs
Implementation
Community input
Security Goals
Formal Model
ProVerif
Properties
Sanity checks
Update
Validation
Formal Analysis
Proof
Attack
Could not prove
No result

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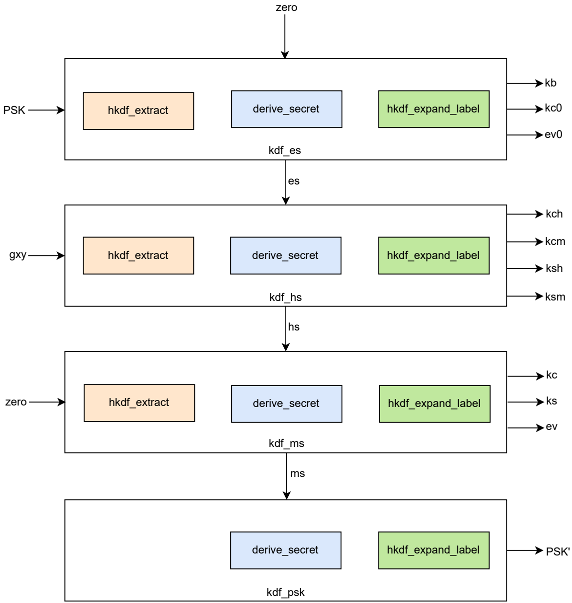
Key Schedule - Overview

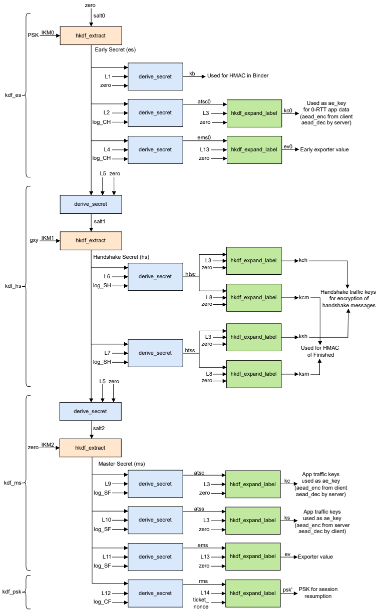


Key Schedule[10]

```
             0
             |
             v
   PSK ->  HKDF-Extract = Early Secret
             |
             +-----> Derive-Secret(., "ext binder" | "res binder", "")
             |                     = binder_key
             |
             +-----> Derive-Secret(., "c e traffic", ClientHello)
             |                     = client_early_traffic_secret
             |
             +-----> Derive-Secret(., "e exp master", ClientHello)
             |                     = early_exporter_master_secret
             v
       Derive-Secret(., "derived", "")
             |
             v
   (EC)DHE -> HKDF-Extract = Handshake Secret
             |
             +-----> Derive-Secret(., "c hs traffic",
             |                     ClientHello...ServerHello)
             |                     = client_handshake_traffic_secret
             |
             +-----> Derive-Secret(., "s hs traffic",
             |                     ClientHello...ServerHello)
             |                     = server_handshake_traffic_secret
             v
       Derive-Secret(., "derived", "")
             |
             v
   0 -> HKDF-Extract = Master Secret
             |
             +-----> Derive-Secret(., "c ap traffic",
             |                     ClientHello...server Finished)
             |                     = client_application_traffic_secret_0
             |
             +-----> Derive-Secret(., "s ap traffic",
             |                     ClientHello...server Finished)
             |                     = server_application_traffic_secret_0
             |
             +-----> Derive-Secret(., "exp master",
             |                     ClientHello...server Finished)
             |                     = exporter_master_secret
             |
             +-----> Derive-Secret(., "res master",
                                   ClientHello...client Finished)
                                   = resumption_master_secret
```

[10] https://datatracker.ietf.org/doc/html/rfc8446#section-7.1

Key Schedule with 2nd Stage



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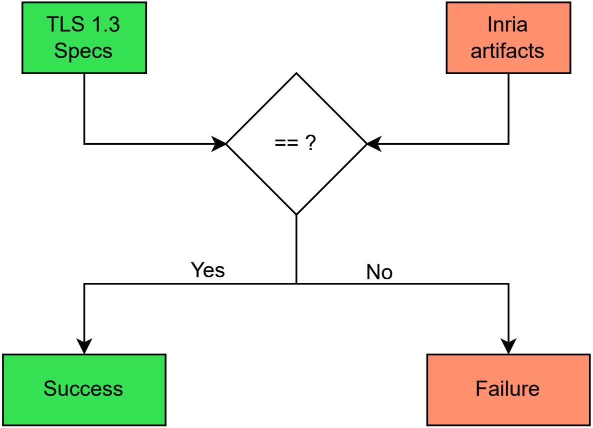
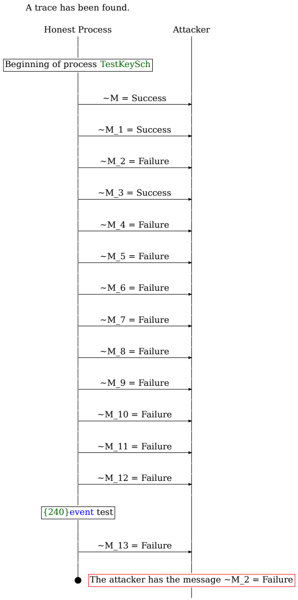
   - Key Schedule
   - Validation of Key Schedule

Validation Framework



Validation Result



Issue 1: Salt for Handshake Secret[11]

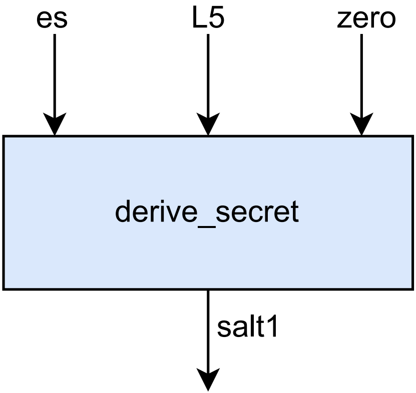


Figure: TLS 1.3 Specs

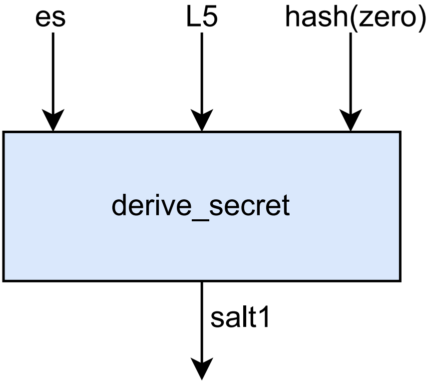


Figure: Inria artifacts

[11] https://github.com/Inria-Prosecco/reftls/issues/7

Issue 2: Salt for Master Secret[12]

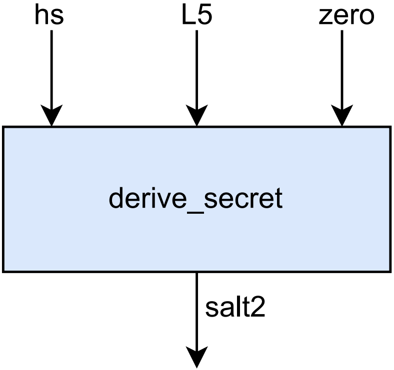


Figure: TLS 1.3 Specs

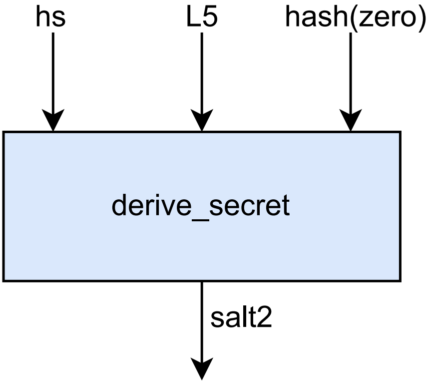


Figure: Inria artifacts

[12] https://github.com/Inria-Prosecco/reftls/issues/7

Issue 3: Master Secret[13]

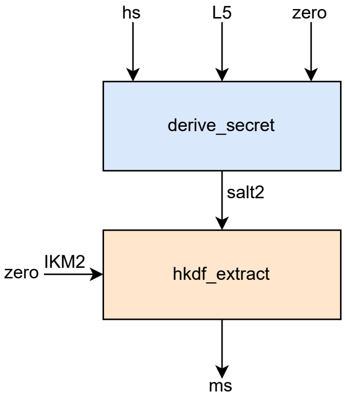


Figure: TLS 1.3 Specs

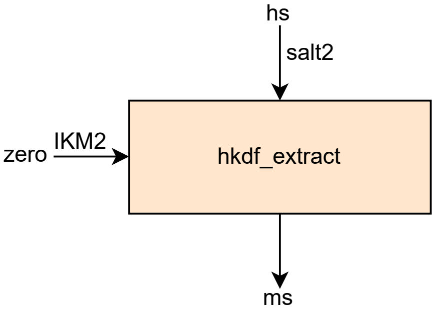


Figure: Inria artifacts

[13] https://github.com/Inria-Prosecco/reftls/issues/6

Ruling out Abstractions

- Ubuntu 20.04 LTS on an Intel Core i7-11800H processor with 64 GB of RAM

Code	**ProVerif 2.04**	**ProVerif 2.05**
Original	6 min 06.634 s	6 min 02.256 s
With issue 1 fixed	5 min 51.682 s	6 min 03.335 s
With issue 2 fixed	7 min 04.472 s	6 min 14.954 s
With issue 3 fixed	7 min 11.434 s	6 min 41.872 s
With all 3 issues fixed	6 min 40.010 s	6 min 31.887 s

Community input

- Paper authors[14]
  - Bruno Blanchet
  - Karthikeyan Bhargavan
  - Nadim Kobeissi
- LURK[15] authors
- IETF TLS WG[16]
- IRTF UFMRG chairs
- CCC attestation SIG[17]
- ...
- IETF 119 Hackathon[18]
- IRTF Crypto Forum RG @ IETF 119[19]

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

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

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

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

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

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

Outline

1. TLS
2. Attestation (RA)
3. Attested TLS (RA+TLS)
4. Contributions
5. Approach and Tool
6. Validation of TLS 1.3
   - Key Schedule
   - Validation of Key Schedule
7. Formal Analysis of Attested TLS
   - Flow
   - Property
8. Summary

Agenda

7. Formal Analysis of Attested TLS
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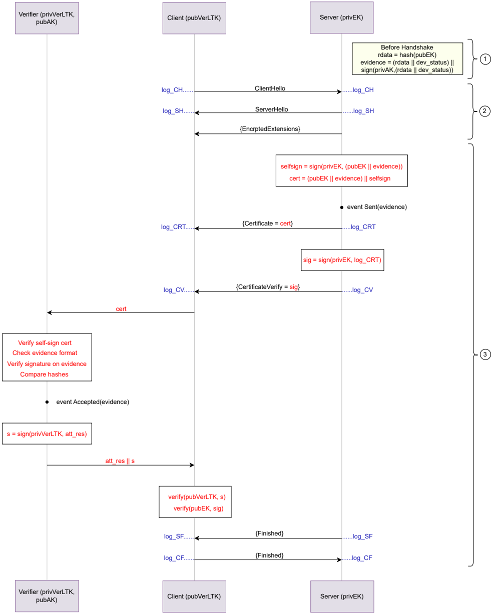
RA-TLS in BC Model



Agenda

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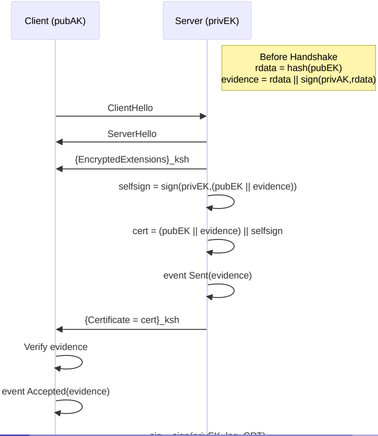
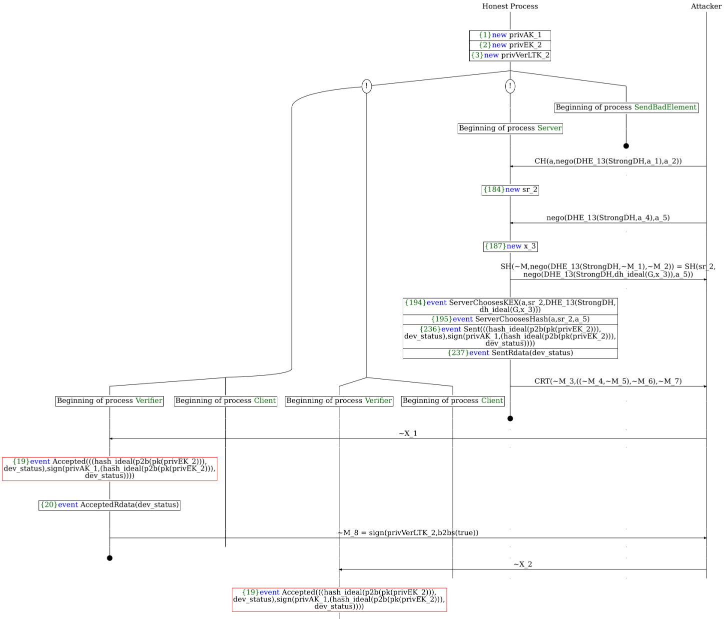
Replay Protection of Evidence

$$query\ ev : bitstring;$$

$$inj - event(Accepted(ev)) ==> inj - event(Sent(ev)) \quad (1)$$



Attack Trace (BC with one-way authenticated channel)



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  - anyone interested?

Key References

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