Design Space and Challenges in Design of Attested TLS Protocols

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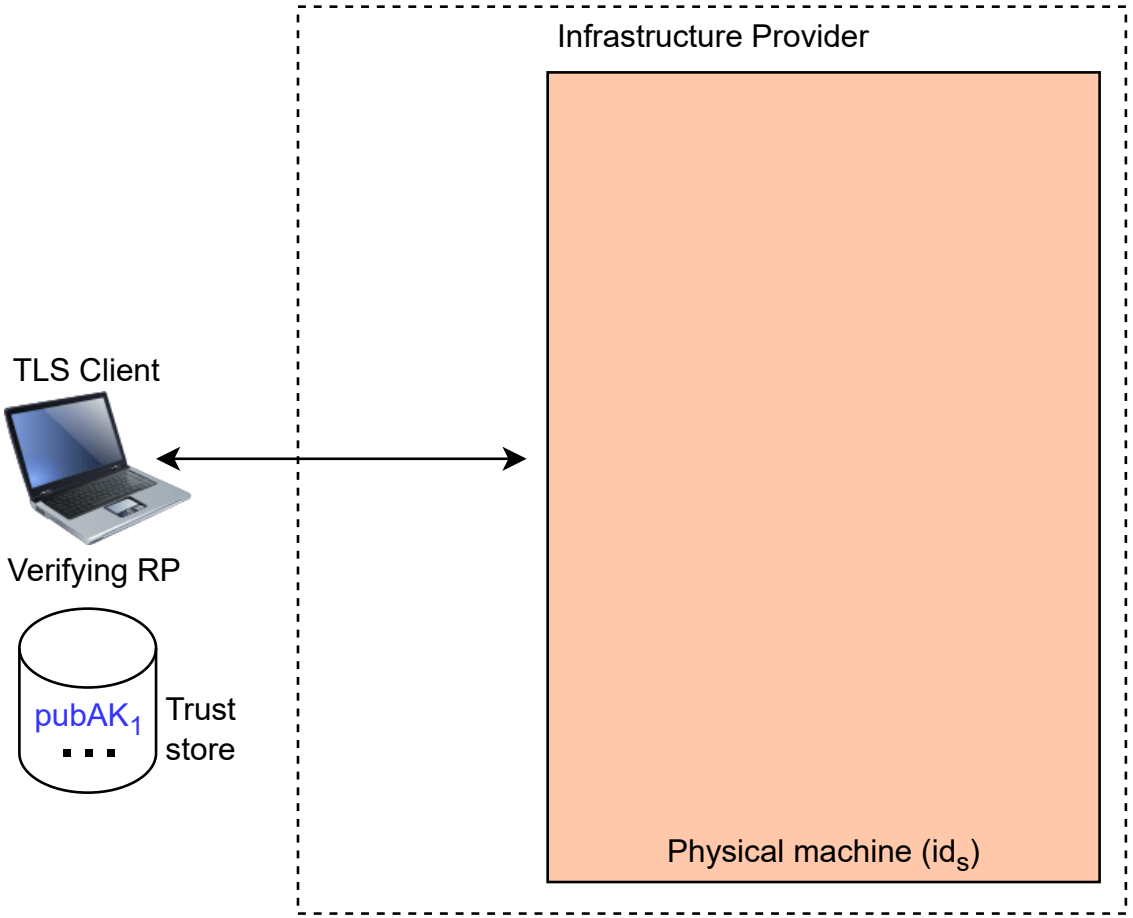
Outline

Use Case (Confidential Computing)



- AK = Attestation Key; pubX = public(X)

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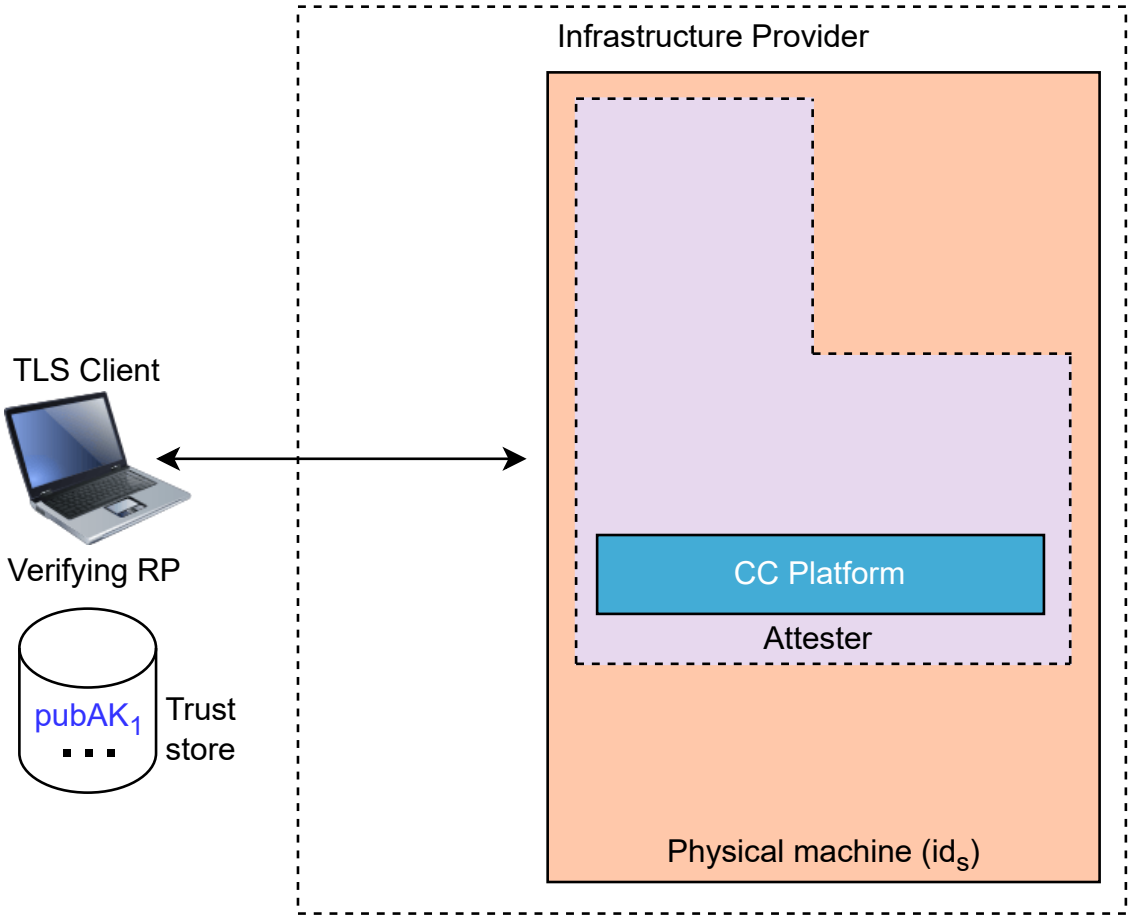

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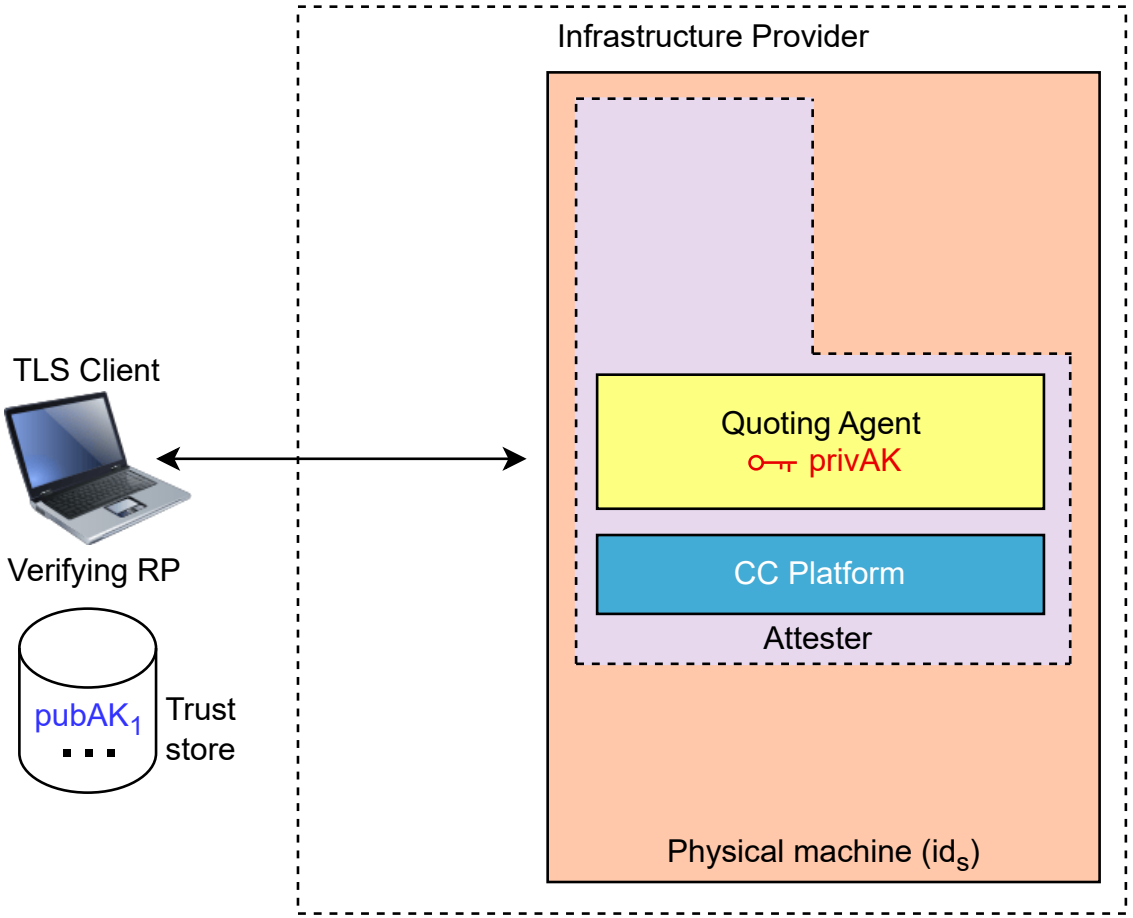

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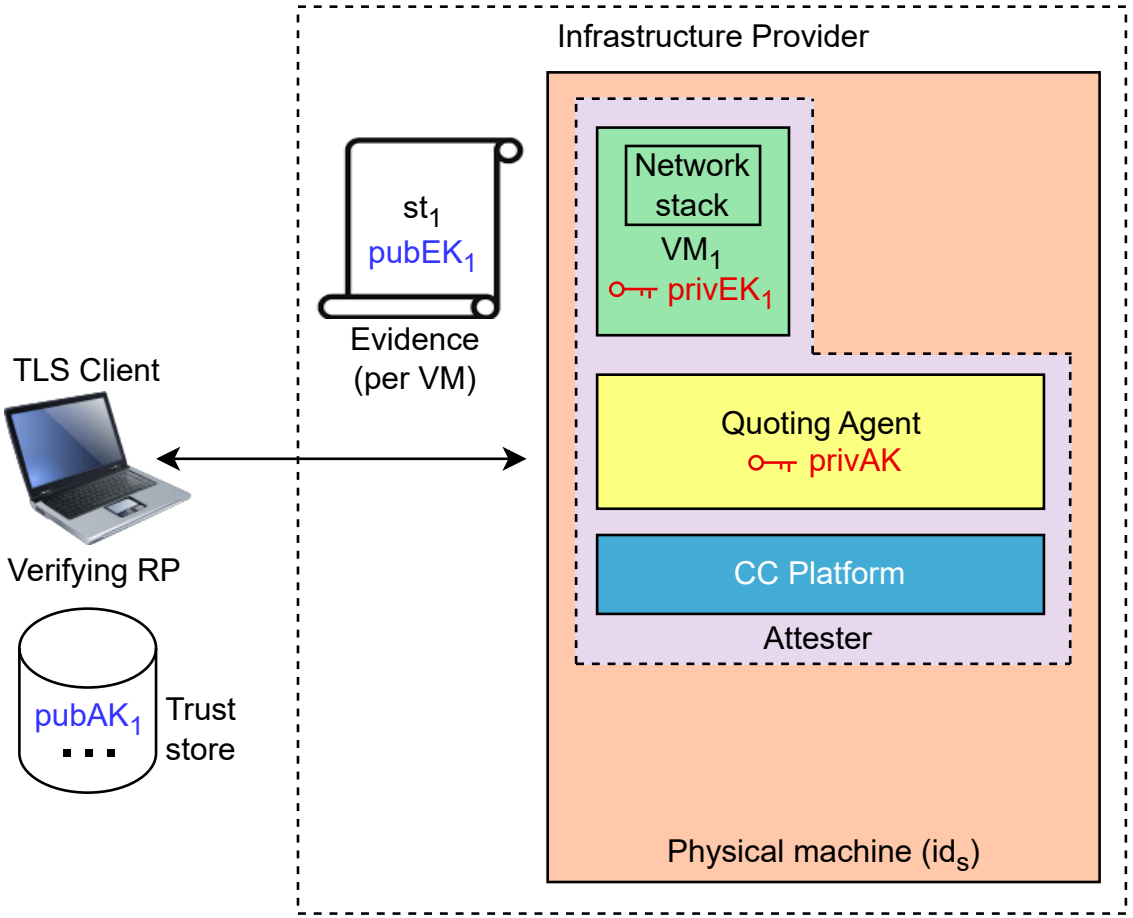

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- EK = Ephemeral Key; *st* = state claims

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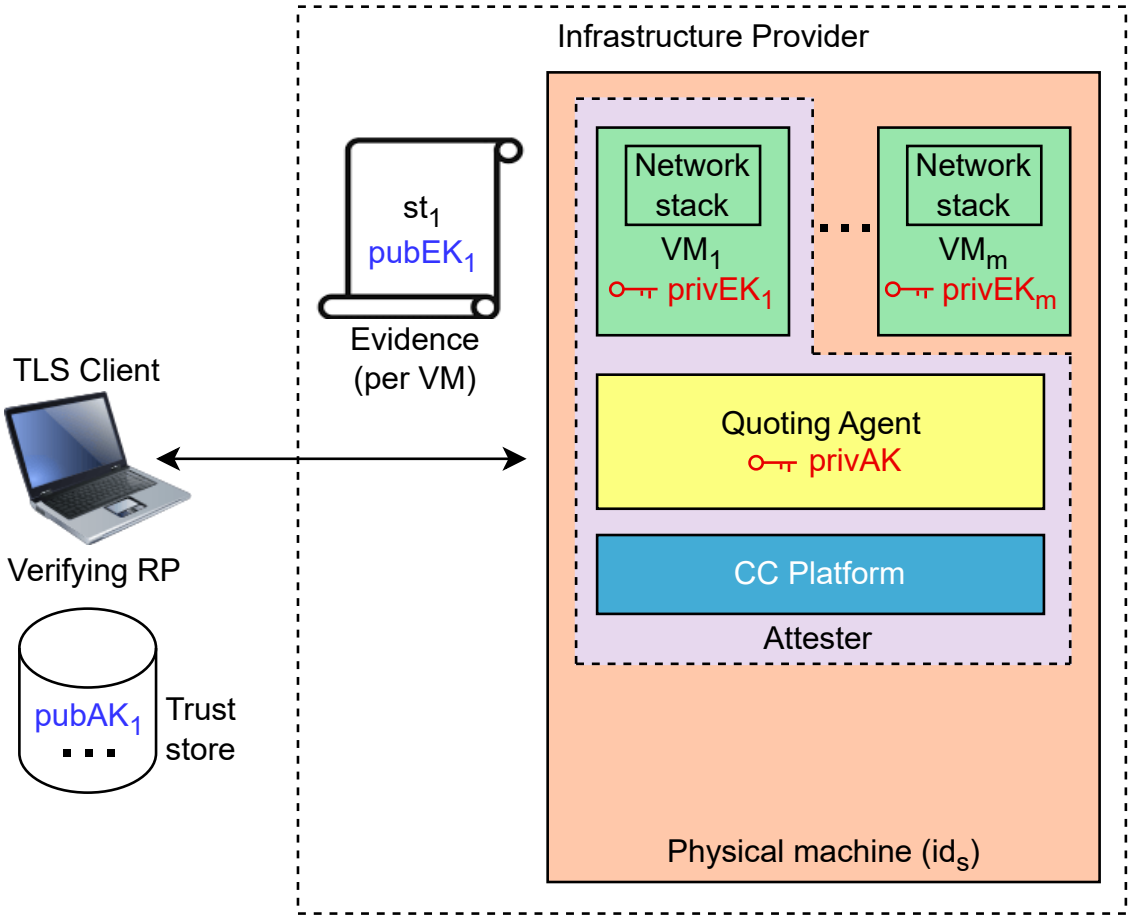

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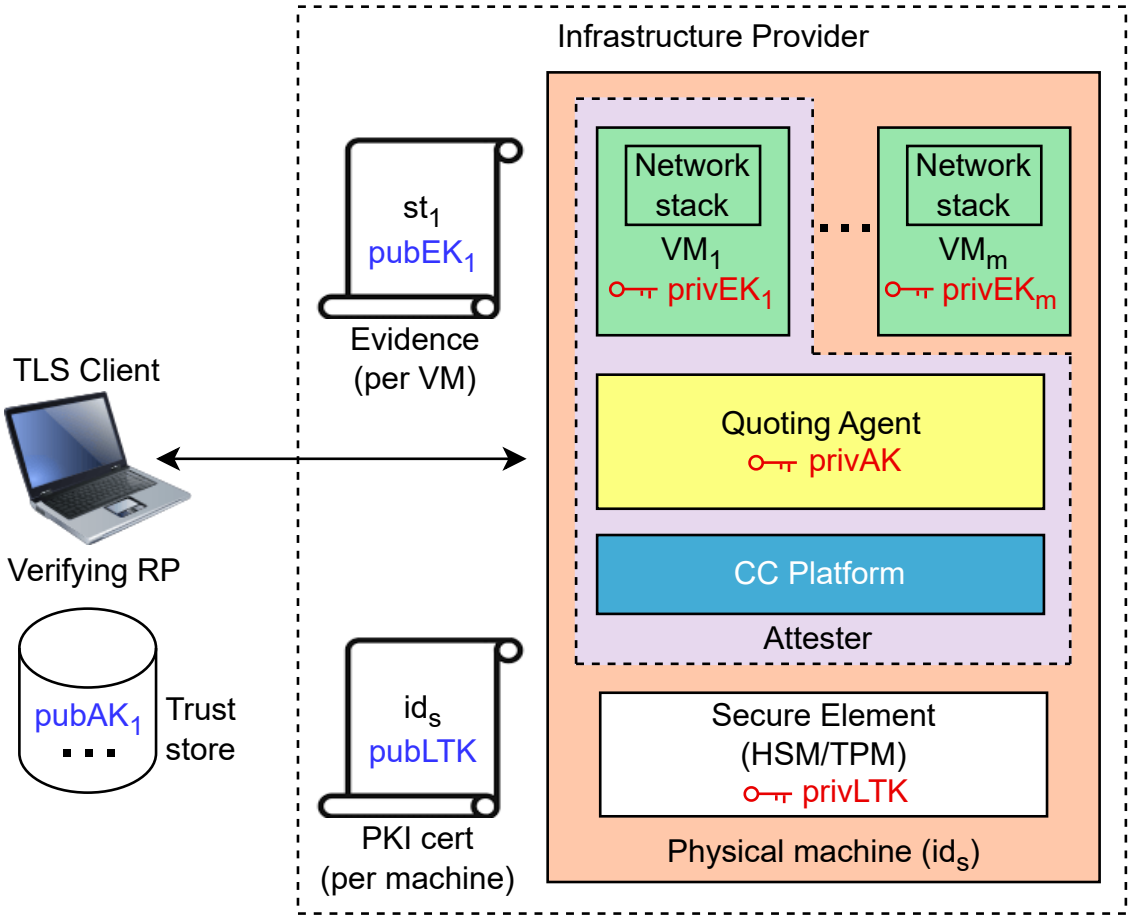

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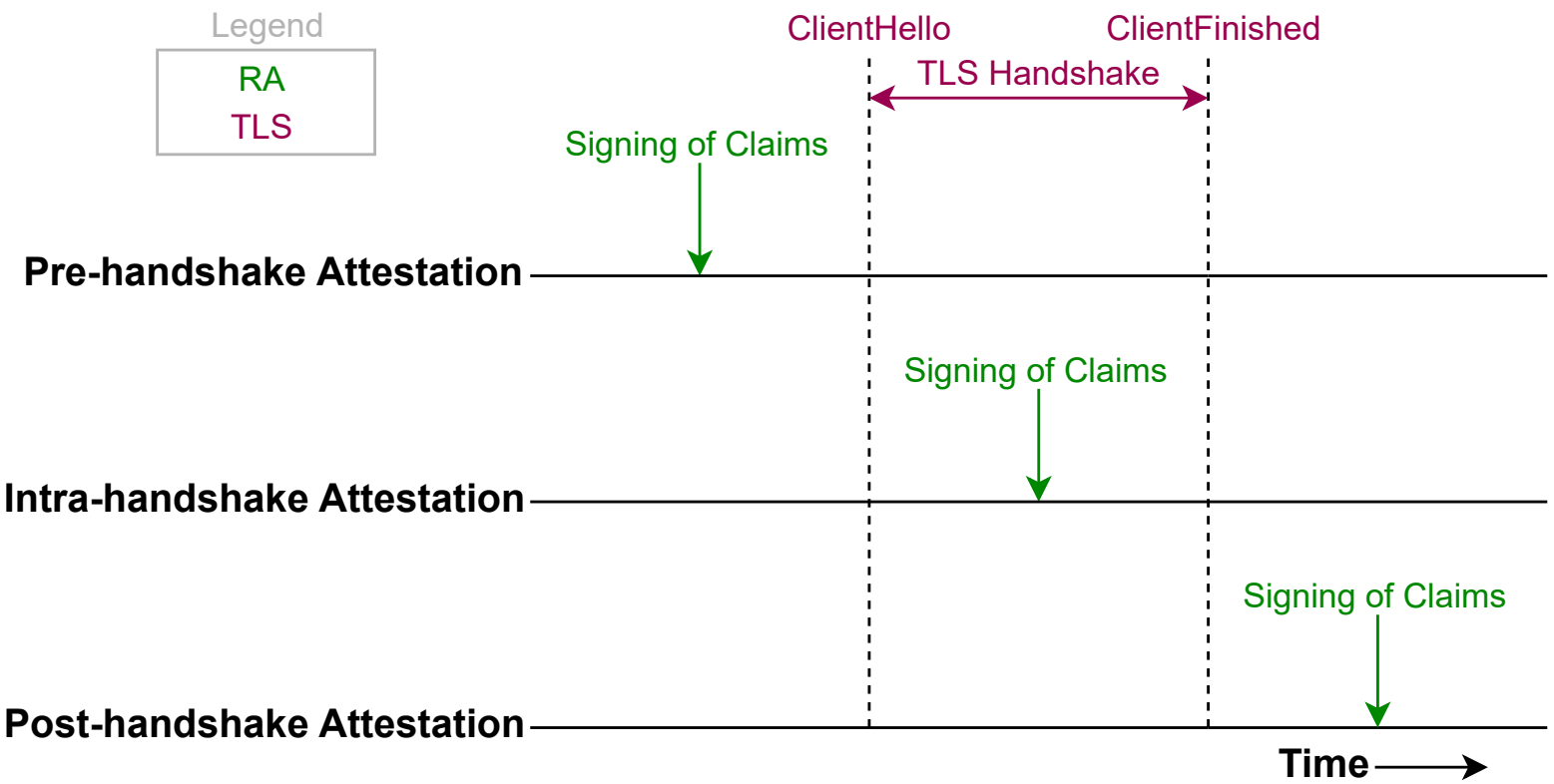
- EK = Ephemeral Key; *st* = state claims
- LTK = Long-Term Key; id_s = identity of server

Design Space



- Pre-handshake: Intel's RA-TLS/Interoperable RA-TLS (IRA-TLS)
- Intra-handshake: draft-fossati-tls-attestation (TLS-a)
- Post-handshake: draft-fossati-seat-expat

Informal Security Goals

- Agreement in Confidential Computing MC yesterday (Link) and discussions afterwards

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- Remote Attestation
  - G-RA1: Integrity of Evidence
  - G-RA2: Freshness of Evidence
    - Binding Evidence to a specific RA interaction
    - Recentness of Evidence generation
  - G-RA3: Establishment of connection with privAK known to adversary
  - G-RA4: Establishment of connection with privEK known to adversary

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- Standard TLS properties
  - G-TLS1: Establishment of connection with `client_write_key` known to adversary
  - G-TLS2: Server authentication

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- Standard TLS properties
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- Composition goals
  - G-C1: Evidence is generated by the same server that is authenticated
    - Correlating Evidence to a specific TLS connection: g^{xy}, *htsc*, *atsc*
  - G-C2: Agreement of all Remote Attestation and TLS parameters

Results for Pre- and Intra-handshake Attestation[1]

- Pre-handshake attestation: Interoperable RA-TLS (IRA-TLS)
- Intra-handshake attestation: draft-fossati-tls-attestation (TLS-a)

Security goal	IRA-TLS	TLS-a
G-RA1: Integrity of Evidence	✓	✓
G-RA2: Freshness of Evidence	×	✓
G-RA3: Protection of Attestation Keys	✓	✓
G-RA4: Protection of Ephemeral Keys	✓	✓
G-TLS1: Protection of Client's Write Key	✓	✓
G-TLS2.1: Server Authentication	×	×
G-TLS2.2: Server Authentication	×	×
G-C1a: Correlation of Evidence to `gxy`	×	×
G-C1b: Correlation of Evidence to `htsc`	×	×
G-C1c: Correlation of Evidence to `atsc`	×	×
G-C2: Agreement of all parameters	×	×

✓ = satisfied; × = not satisfied.

[1] Details in `https://datatracker.ietf.org/doc/slides-124-ufmrg-formal-analysis-of-attested-tls-protocols`

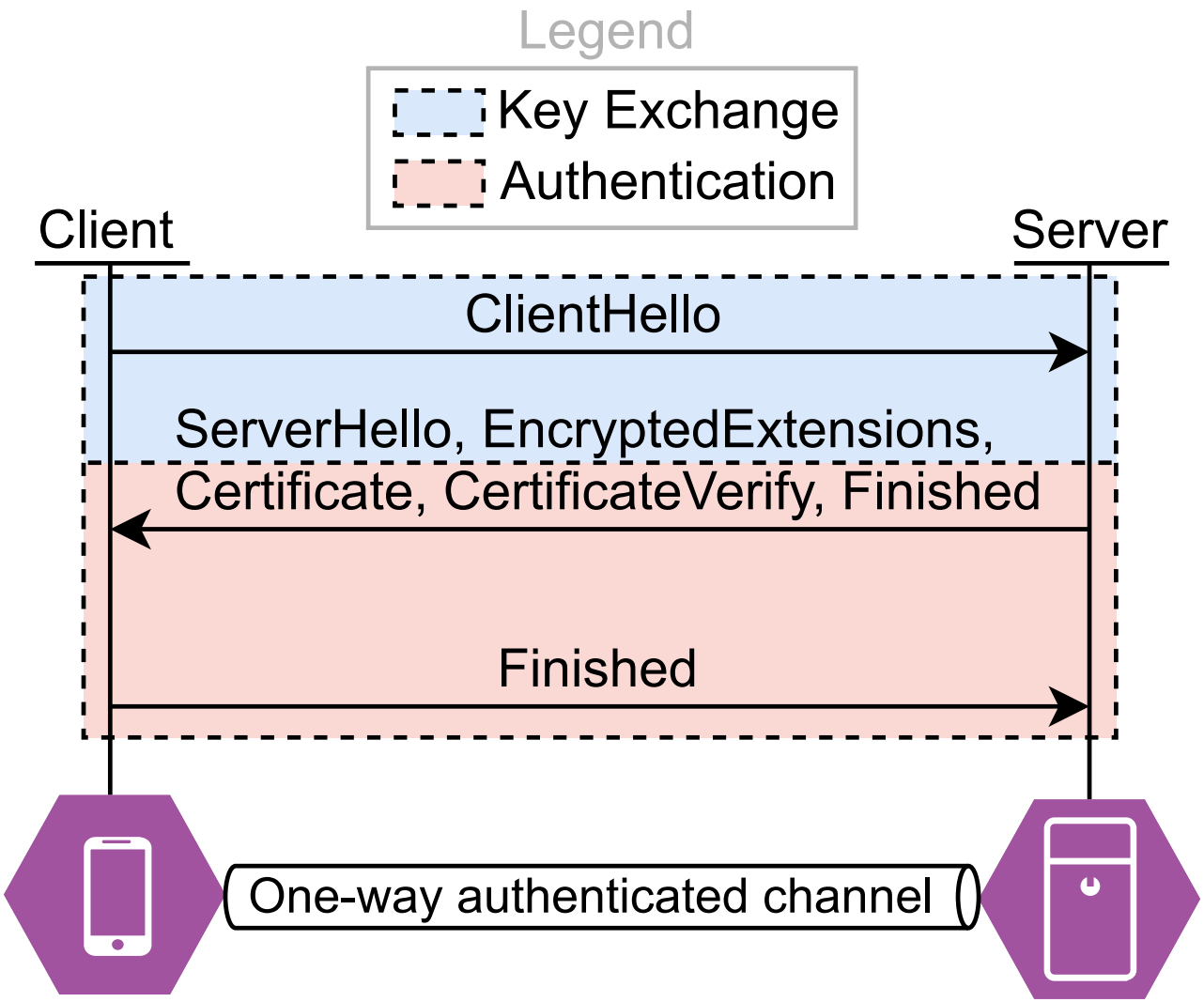
Results for Proposed Solutions in Intra-handshake Attestation

- Sol.1: Modify CertificateVerify message
- Sol.2: Two CertificateVerify messages
- Sol.3: New signature algorithm
- Sol.4: New Attestation message
- Sol.5: Modify CertificateVerify message + define new exporter

Security goal	Sol.1	Sol.2	Sol.3	Sol.4	Sol.5
G-RA1: Integrity of Evidence	✓	✓	✓	✓	✓
G-RA2: Freshness of Evidence	✓	✓	✓	✓	✓
G-RA3: Protection of Attestation Keys	✓	✓	✓	✓	✓
G-RA4: Protection of Ephemeral Keys	✓	✓	✓	✓	✓
G-TLS1: Protection of Client's Write Key	✓	✓	✓	✓	✓
G-TLS2.1: Server Authentication	✓	✓	✓	✓	✓
G-TLS2.2: Server Authentication	✓	✓	✓	✓	✓
G-C1a: Correlation of Evidence to `gxy`	×	×	×	×	✓
G-C1b: Correlation of Evidence to `htsc`	×	×	×	×	✓
G-C1c: Correlation of Evidence to `atsc`	×	×	×	×	×
G-C2: Agreement of all parameters	✓	✓	✓	✓	✓

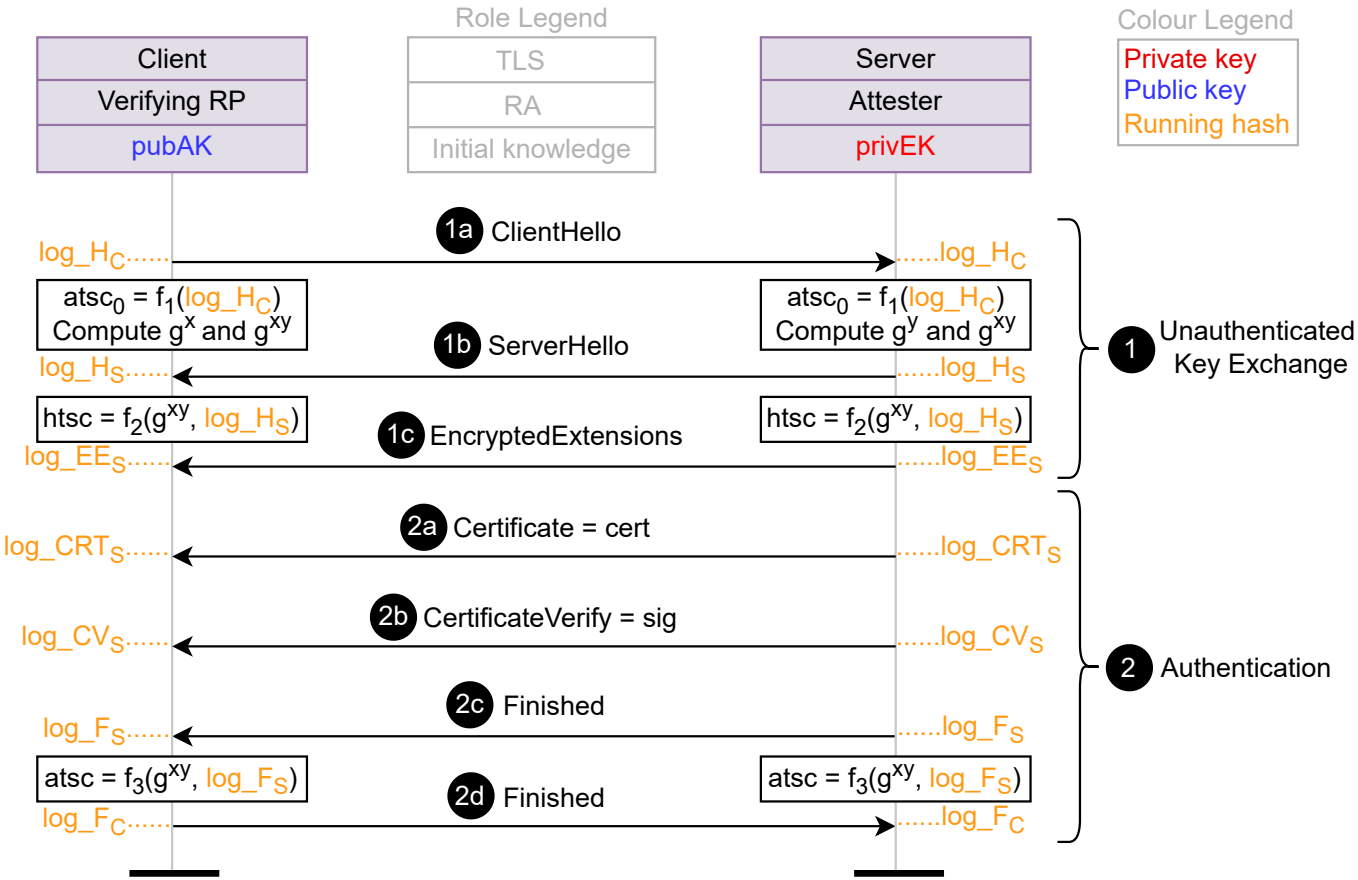
Standard TLS 1.3 (RFC8446bis)

- Server authentication by default
- Optional client authentication



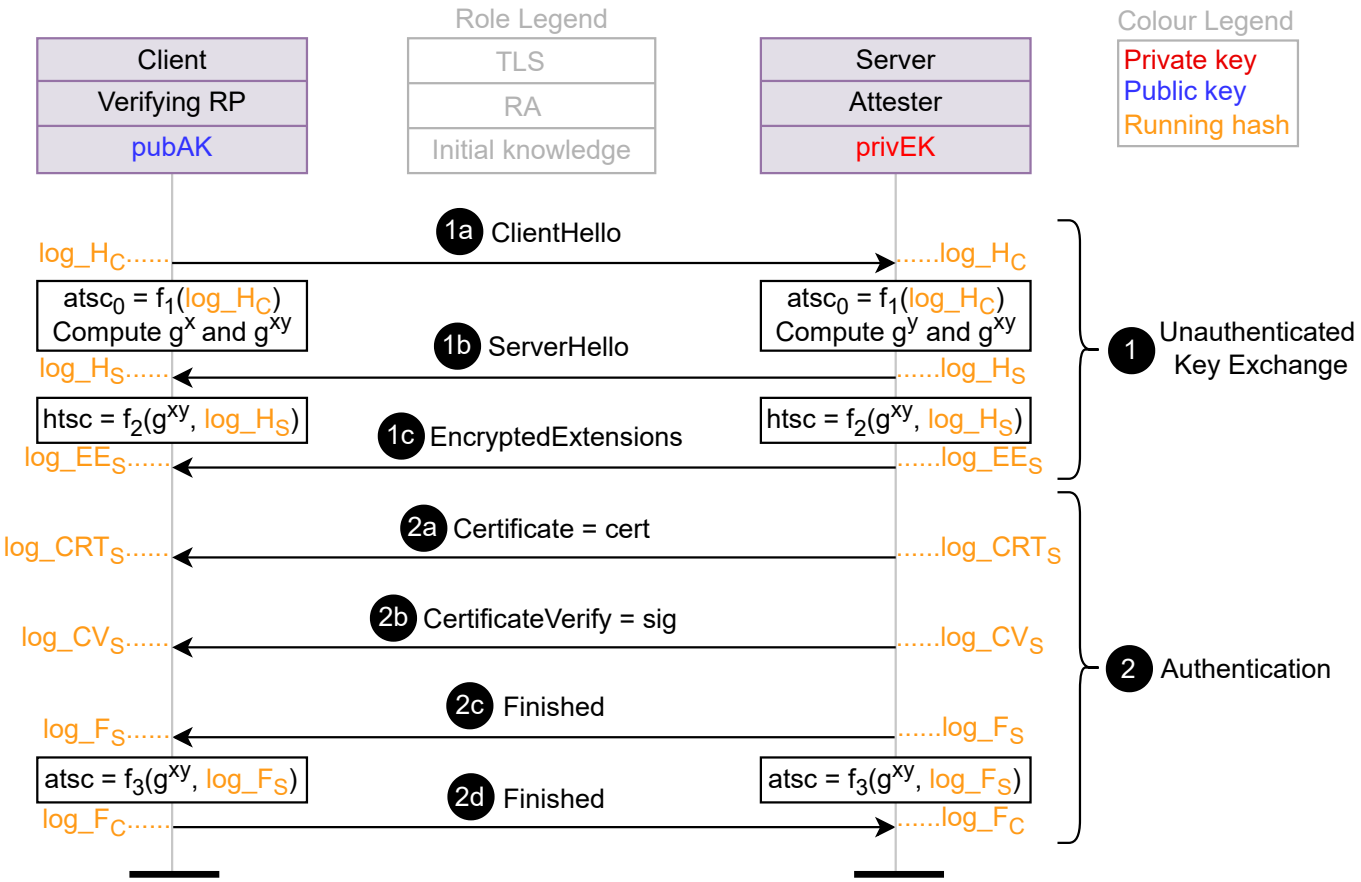
Outline

Strong Binding vs. Relay of Evidence (Abstracted)



- g^{xy}: Shared Diffie-Hellman key; f_1, f_2, f_3: Key derivation functions
- Discussion: Correlating Evidence to `htsc` vs. `atsc`
  - Running hash $\Longrightarrow$ `atsc` transitively includes all contributions in `htsc`
  - `atsc` provides stronger binding and avoids relay attacks.

Strong Binding vs. Relay of Evidence (Abstracted)



- `htsc`: used for encryption of clientFinished message (2d).
  - Irrelevant for security goals
- `atsc`: used for encryption of application data (client's secret, e.g., decryption key)
  - Relevant for security goals

Outline

Summary

- Pre- and intra-handshake attestation (draft-fossati-tls-attestation) are not suitable choices for standardization. (Formal proof of insecurity)

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- Key insights
  - Need infrastructure identity to prevent diversion attacks
  - Cryptographic binding of RA and TLS is critical to prevent relay attacks
  - Need VM identity to prevent replication attacks
  - One of the most challenging protocols of the IETF: formal analysis is critical to the success.

Summary

- Pre- and intra-handshake attestation (draft-fossati-tls-attestation) are not suitable choices for standardization. (Formal proof of insecurity)
- Key insights
  - Need infrastructure identity to prevent diversion attacks
  - Cryptographic binding of RA and TLS is critical to prevent relay attacks
  - Need VM identity to prevent replication attacks
  - One of the most challenging protocols of the IETF: formal analysis is critical to the success.
- Part of formal analysis accepted at AsiaCCS
- WiP: post-handshake attestation, i.e., draft-fossati-seat-expat
  - Formal analysis in ProVerif
  - Implementation in RustIs (Peg Jones)
  - Implementation in BoringSSL (Pavel Nikonorov)
- Questions for discussion:
  - Any other (verifiable) security goals?
  - `htsc` vs. `atsc`?
  - Any other solution?

Links to Resources

- Wiki page
  - `github.com/EuroProofNet/ProgramVerification/wiki/AttestedTLS`
- Formal proof of insecurity of pre- and intra-handshake attestation
  - `github.com/CCC-Attestation/formal-spec-id-crisis`
- Post-handshake attestation draft
  - `datatracker.ietf.org/doc/draft-fossati-seat-expat/`
- Attestation in Arm CCA and Intel TDX
  - `github.com/CCC-Attestation/formal-spec-TEE`
- Security considerations of remote attestation
  - `datatracker.ietf.org/doc/draft-sardar-rats-sec-cons/`
- IETF SEAT WG
  - `datatracker.ietf.org/wg/seat/about/`
- Technical Concepts
- Validation of TLS 1.3 Key Schedule
- General Approach
- Weekly meetings
  - `github.com/tls-attestation#meetings`

ACK

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- Thomas Fossati (Linaro)
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- Simon Frost (Arm)
- Ned Smith (Intel)
- Carsten Weinhold (Barkhausen Institut)
- Michael Roitzsch (Barkhausen Institut)
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- Werner Staub (CORE Association)
- Paul Wouters (Aiven)
- Dennis Jackson (Mozilla)
- Peg Jones (Flashbots)

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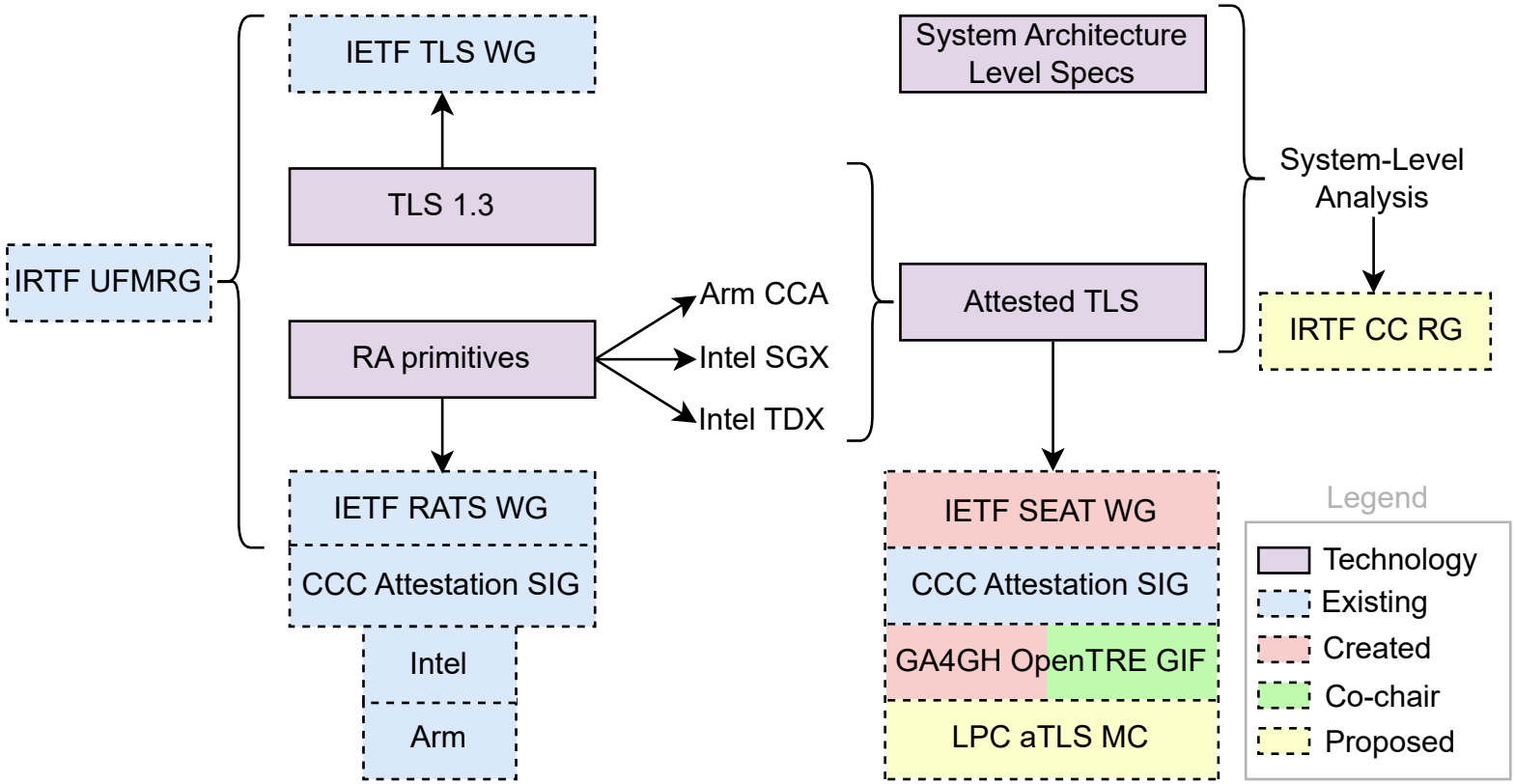
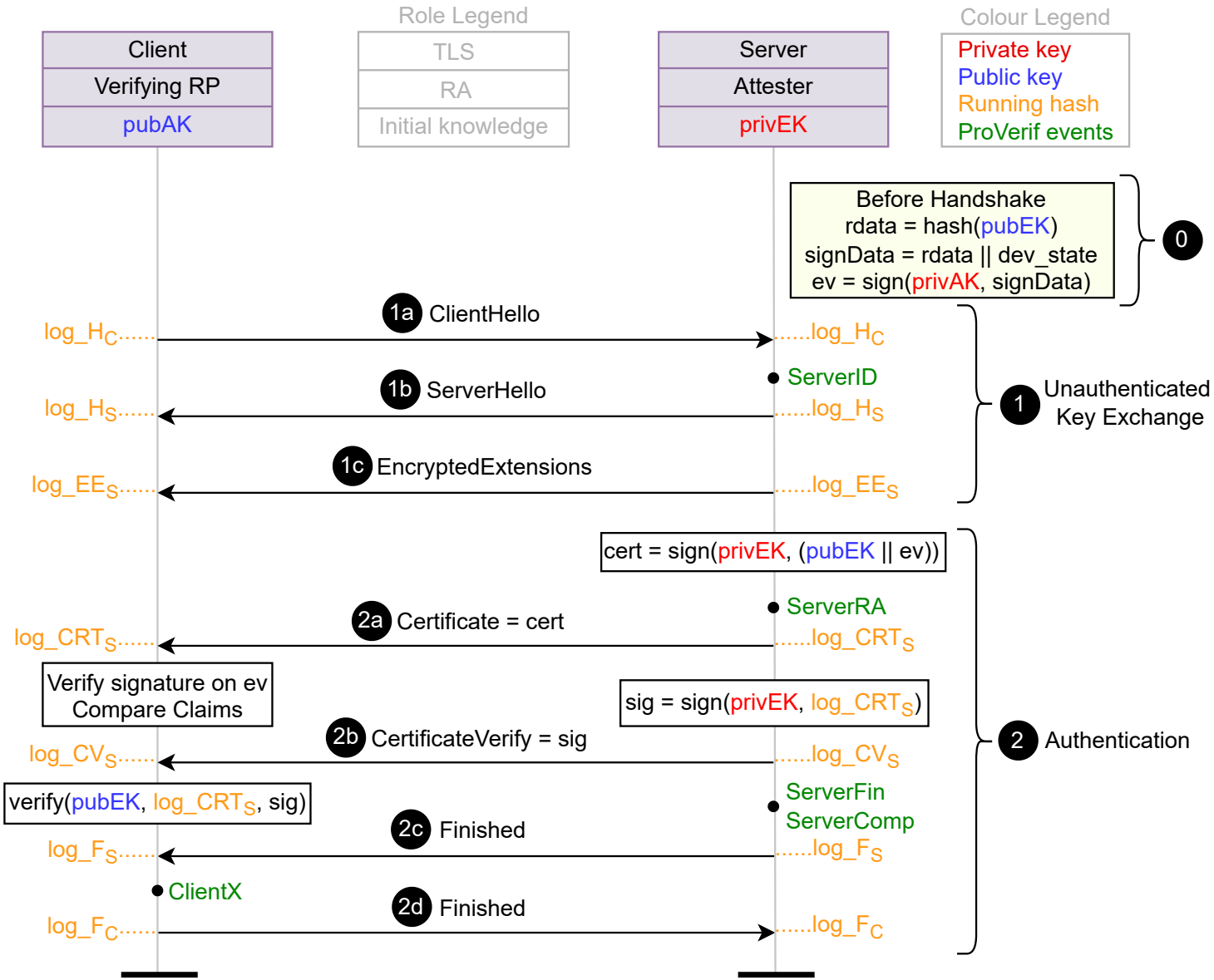
Big Picture



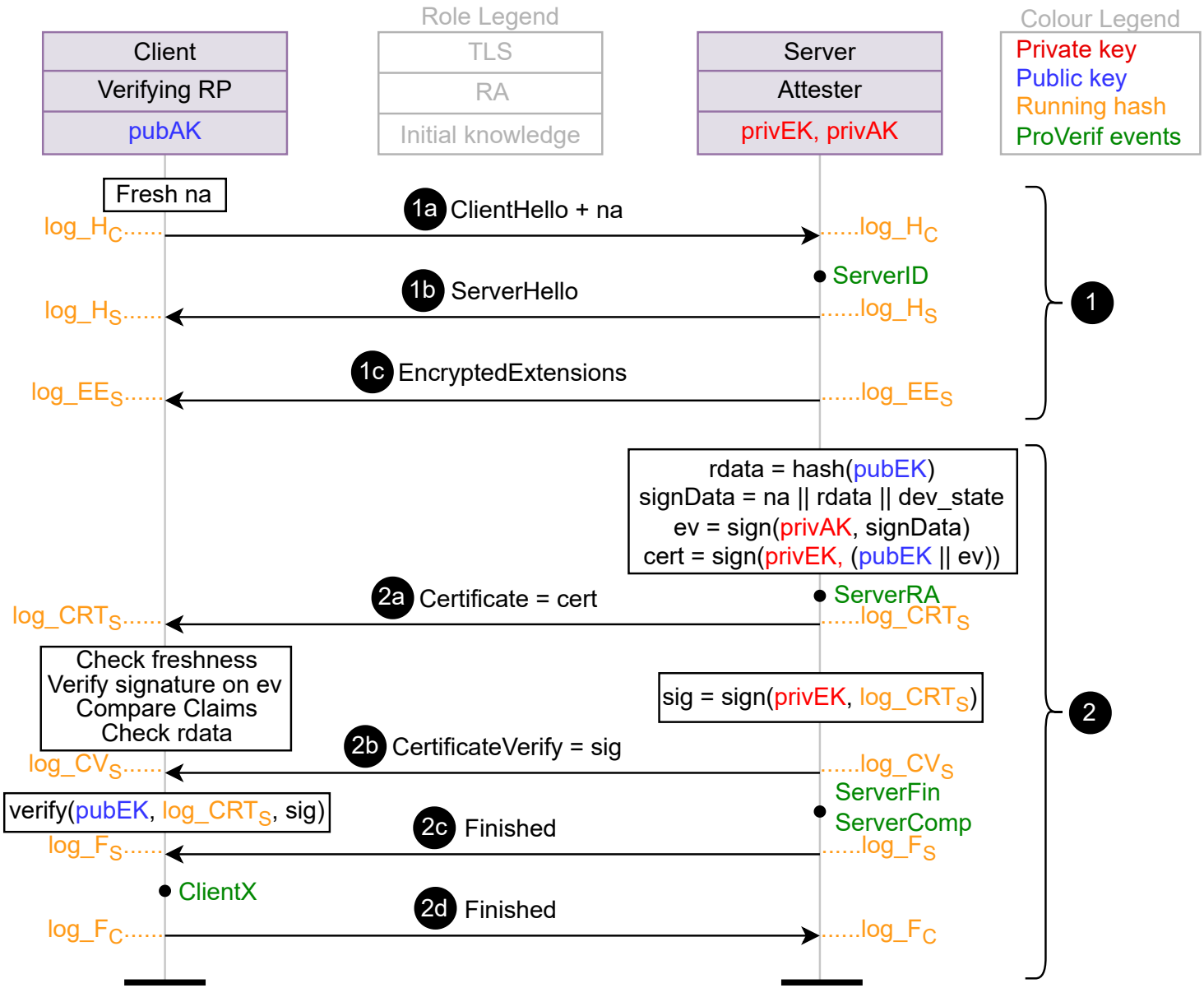
- IETF: Internet Engineering Task Force
- IRTF: Internet Research Task Force
- CCC: Confidential Computing Consortium
- GA4GH: Global Alliance for Genomics and Health
- RATS: Remote ATtestation ProcedureS
- TLS: Transport Layer Security
- SEAT: Secure Evidence and Attestation Transport

- UFMRG: Usable Formal Methods Research Group
- CC: Confidential Computing
- WG: Working Group
- RG: Research Group
- aTLS: Attested TLS
- SIG: Special Interest Group
- OpenTRE: Trusted Research Environment Open Suite

IRA-TLS


Role Legend
TLS
RA
Initial knowledge
Colour Legend
Private key
Public key
Running hash
ProVerif events
Client
Verifying RP
pubAK
Server
Attester
privEK
Before Handshake
rdata = hash(pubEK)
signData = rdata || dev_state
ev = sign(privAK, signData)
0
1a ClientHello
log_H_C
log_H_C
ServerID
1b ServerHello
log_H_S
log_H_S
1c EncryptedExtensions
log_EE_S
log_EE_S
1 Unauthenticated Key Exchange
cert = sign(privEK, (pubEK || ev))
ServerRA
2a Certificate = cert
log_CRT_S
log_CRT_S
Verify signature on ev
Compare Claims
sig = sign(privEK, log_CRT_S)
2b CertificateVerify = sig
log_CV_S
log_CV_S
verify(pubEK, log_CRT_S, sig)
ServerFin
ServerComp
2c Finished
log_F_S
log_F_S
ClientX
2d Finished
log_F_C
log_F_C
2 Authentication

TLS-a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Private key
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Running hash
ProVerif events
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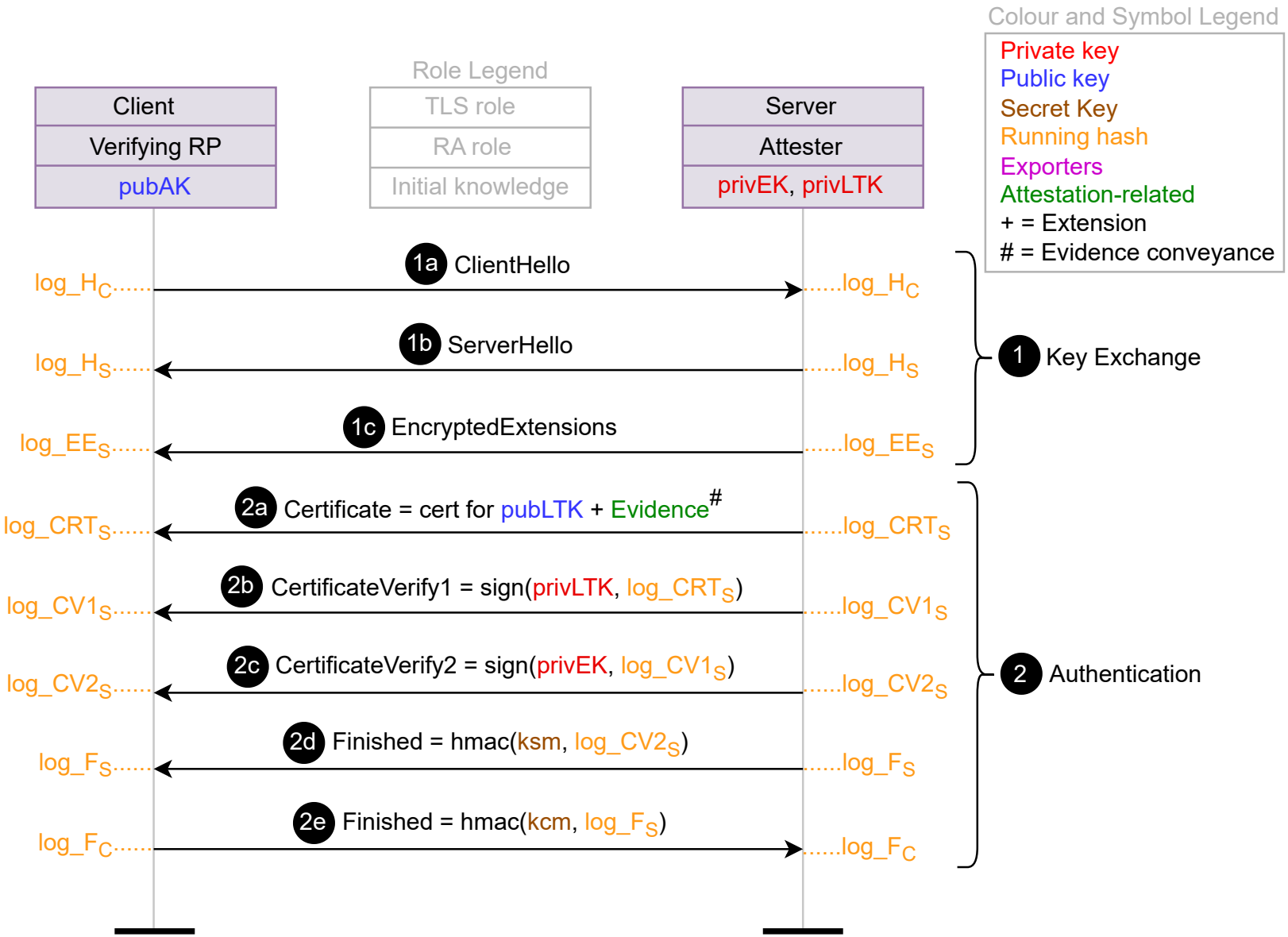
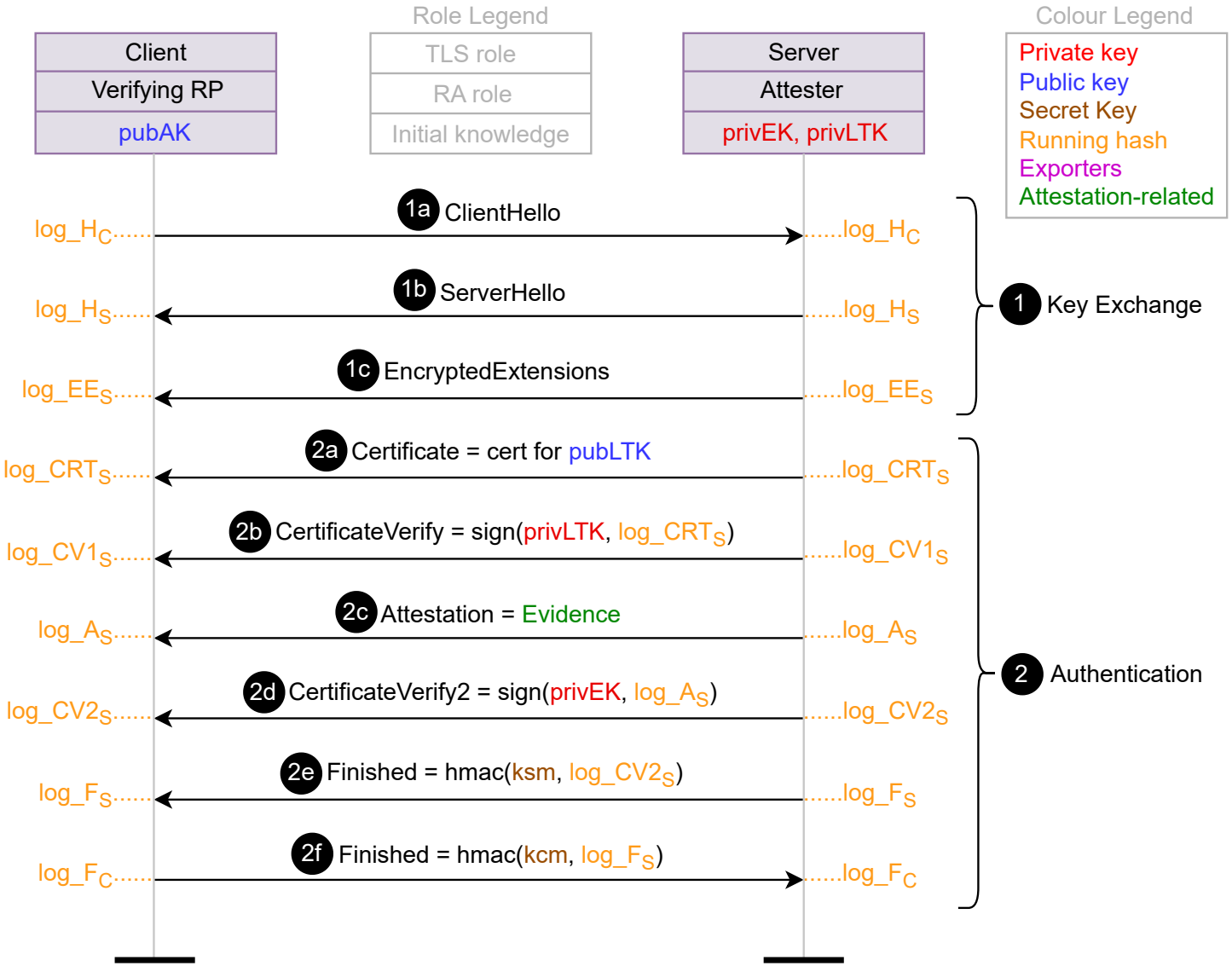
Verifying RP
pubAK
Server
Attester
privEK, privAK
Fresh na
log_H_C
1a ClientHello + na
log_H_C
ServerID
1b ServerHello
log_H_S
log_H_S
1c EncryptedExtensions
log_EE_S
log_EE_S
1
rdata = hash(pubEK)
signData = na || rdata || dev_state
ev = sign(privAK, signData)
cert = sign(privEK, (pubEK || ev))
2a Certificate = cert
ServerRA
log_CRT_S
log_CRT_S
Check freshness
Verify signature on ev
Compare Claims
Check rdata
sig = sign(privEK, log_CRT_S)
2b CertificateVerify = sig
log_CV_S
log_CV_S
ServerFin
ServerComp
verify(pubEK, log_CRT_S, sig)
2c Finished
log_F_S
log_F_S
ClientX
2d Finished
log_F_C
log_F_C
2

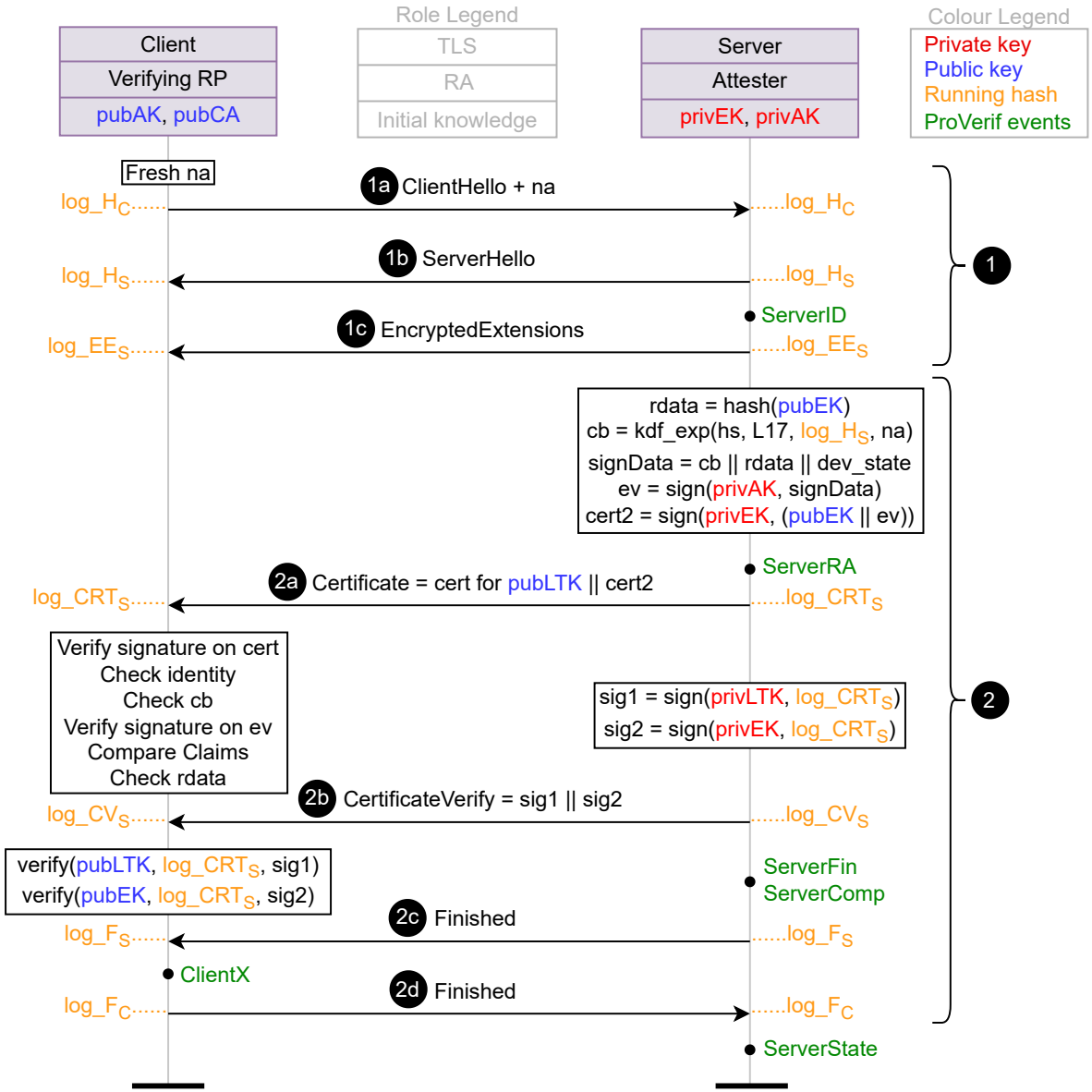
Sol. 2: Two CertificateVerify Messages



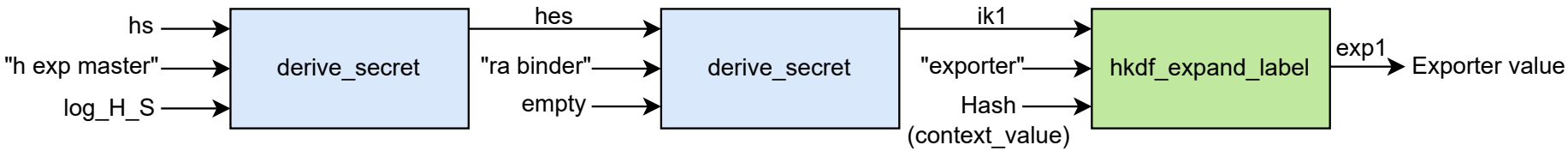
Sol. 4: New Attestation Message



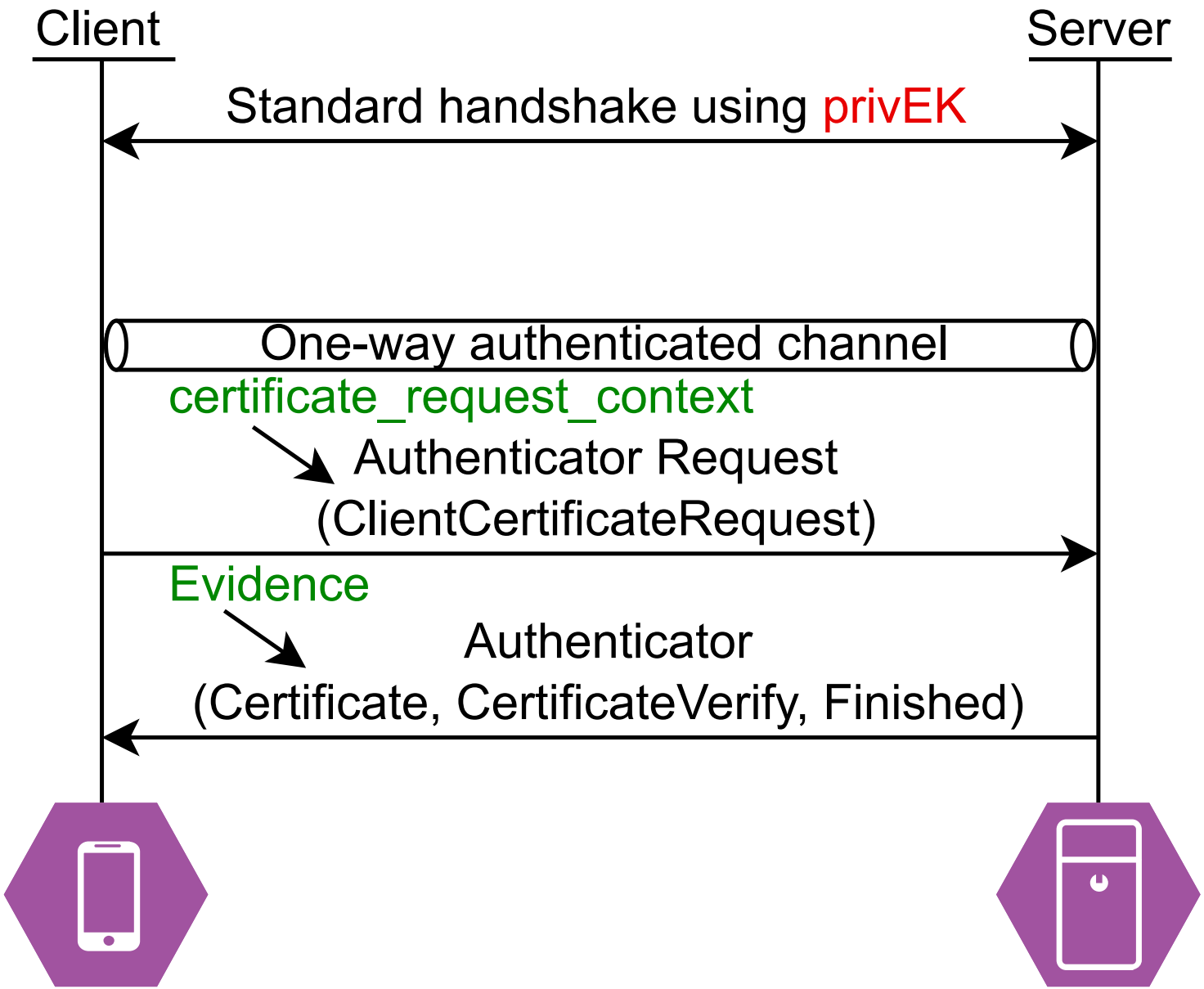
Sol. 5: Cryptographic Binding



Sol. 5 (cont.): Cryptographic Binding



Proposal for Post-handshake Attestation (RFC 9261)



Post-handshake Flow

1. Authenticator Request
   - Unique *certificate_request_context* within connection
2. Evidence based on this context and *Exported Keying Material (EKM)*
3. Authenticator
   - Certificate message extended with Evidence
   - CertificateVerify as in RFC 9261
   - Finished as in RFC 9261
4. Validation: additionally appraise Evidence