Automated Analysis of TLS 1.3

0-RTT, Resumption and Delayed Authentication

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mozilla

Where our work fits in

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Dowling et al. [draft-05]
Kohlweiss et al. [draft-05]
Krawczyk and Wee [OPTLS]
Dowling et al. [draft-10]

We are here!

Motivation and approach

TLS 1.3 designed to be more efficient than TLS 1.2:

- 0-RTT handshake mode.
- PSK mode.
- Delayed client authentication.

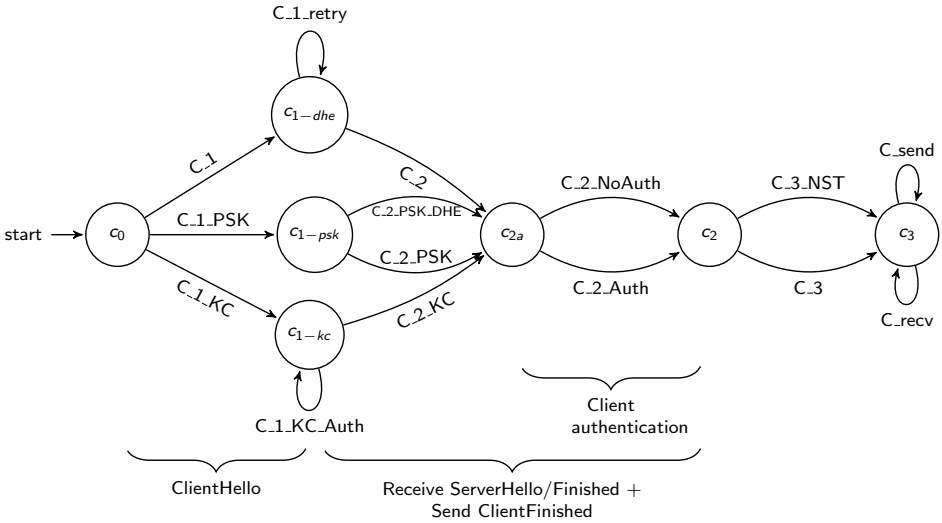
Our goal

Improve the security of TLS 1.3 by analysing the specification using state-of-the-art formal analysis methods.

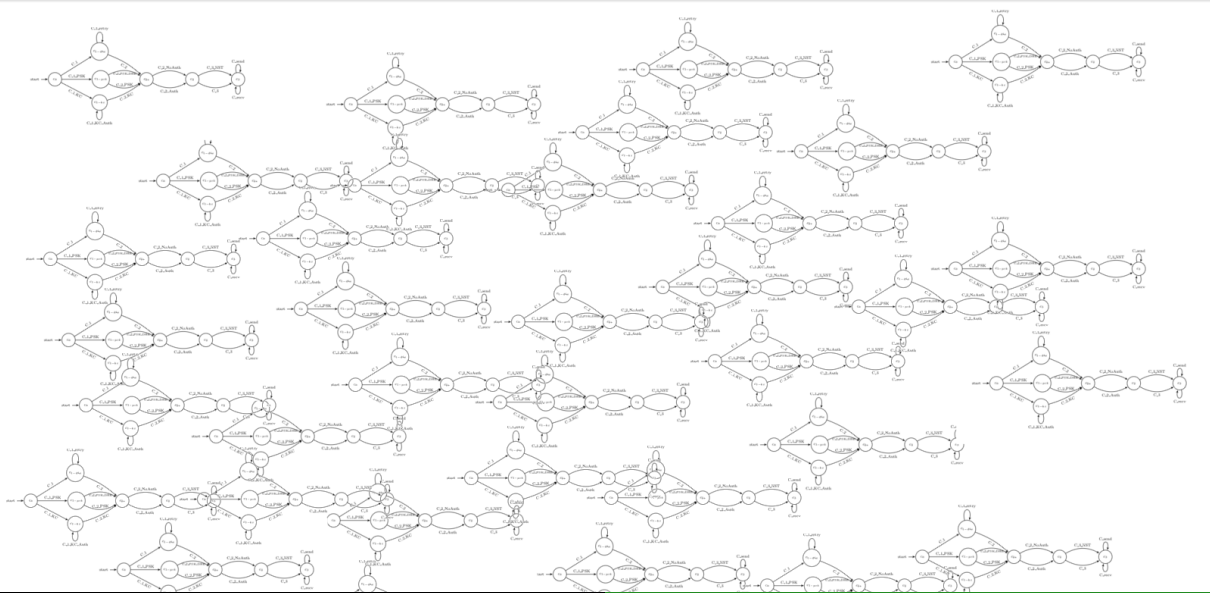
We focus on interaction attacks:

- Perfect cryptography assumption.
- Dolev-Yao attacker.

Building a model. Client state machine



Unbounded number of concurrent sessions



Tamarin

We encoded our model for use in the Tamarin prover:

- State-of-the-art tool for automated protocol analysis.
  - Loops.
  - Branches.
  - Symbolic Diffie-Hellman.
- However, requires considerable user interaction for very complex models.

Verification

We verified the core properties of TLS 1.3 revision 10 as an authenticated key exchange protocol:

- Secrecy of session keys.
  - Forward secrecy included.
- Unilateral and mutual authentication.
- Integrity of handshake messages.

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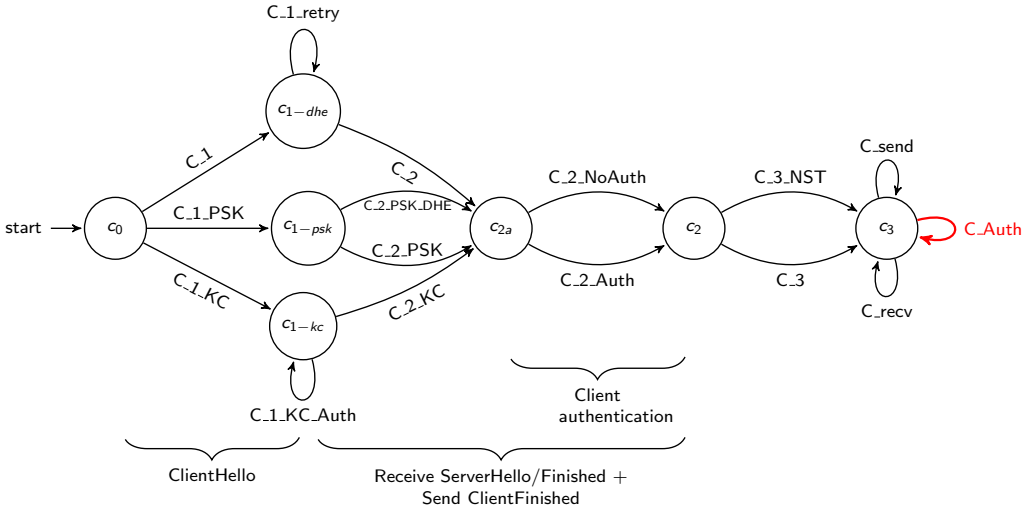
Is it safe to include delayed client authentication in revision 10?

Attacking client authentication

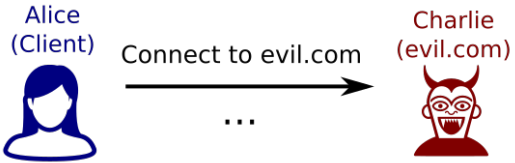


Attacking client authentication

Alice
(Client)

Charlie
(evil.com)

Attacking client authentication



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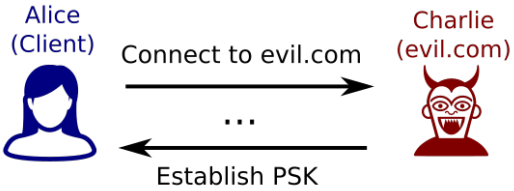

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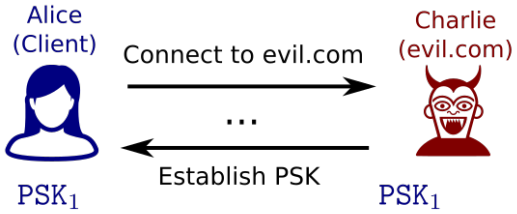

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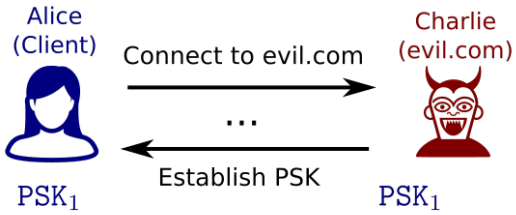

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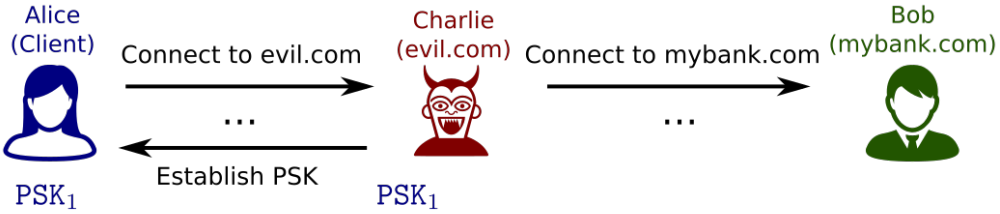

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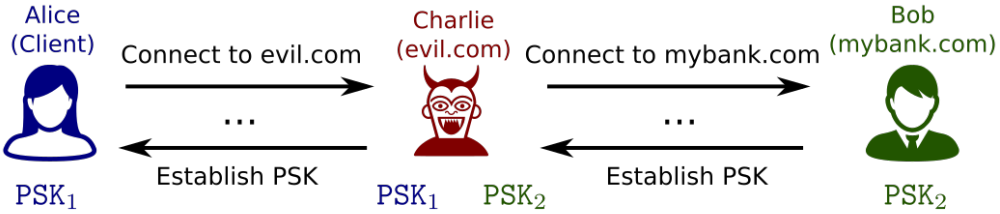

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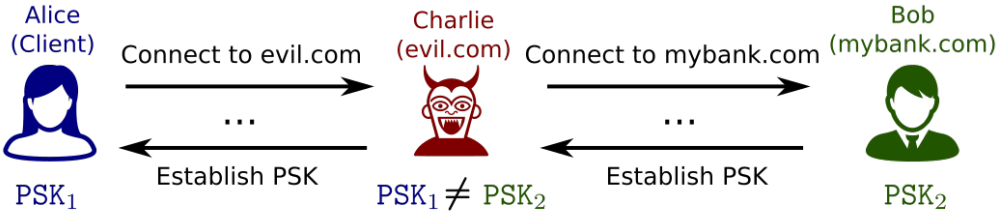

Attacking client authentication

$$\texttt{session\_hash} = H(nc \qquad)$$

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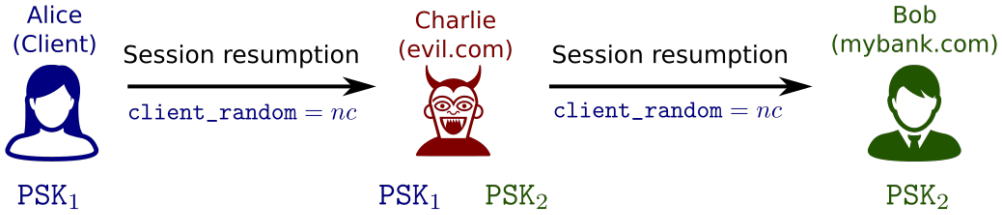

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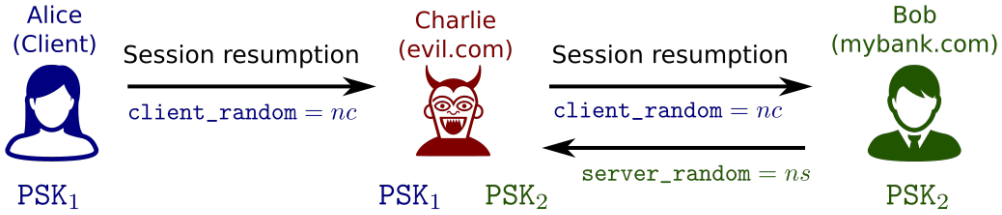

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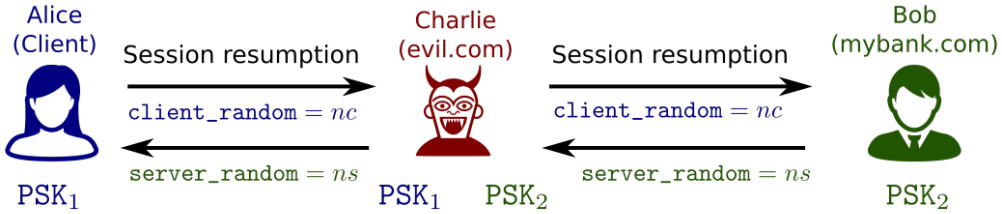

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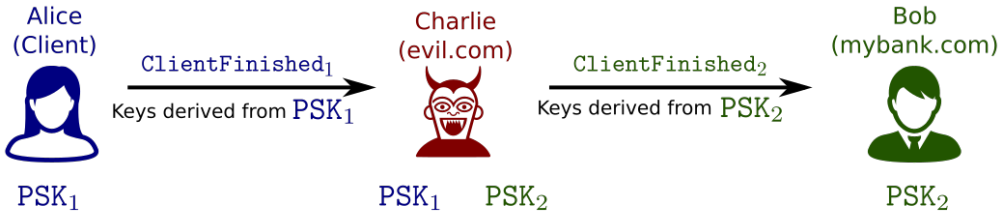

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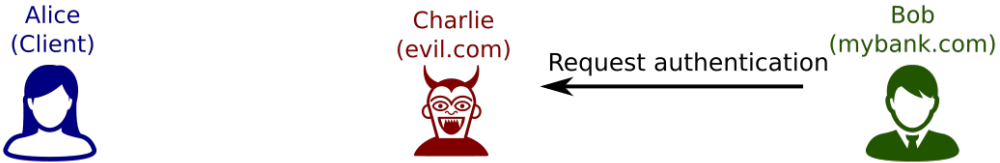

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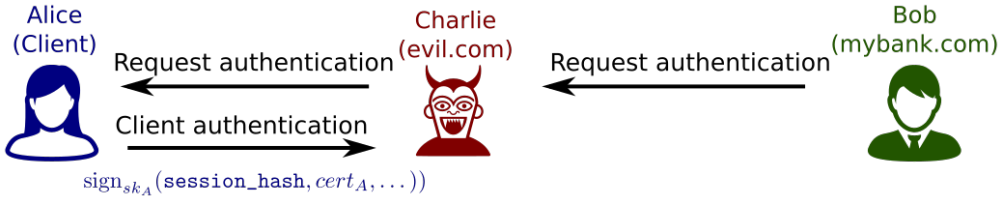

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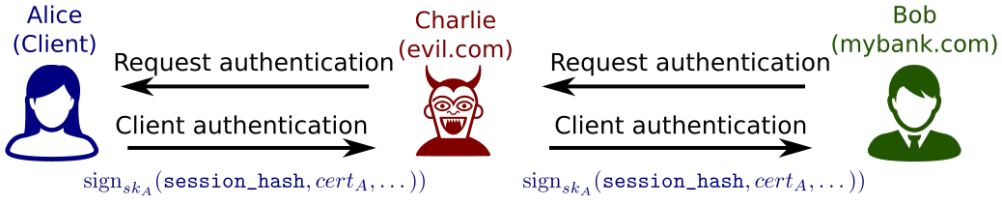

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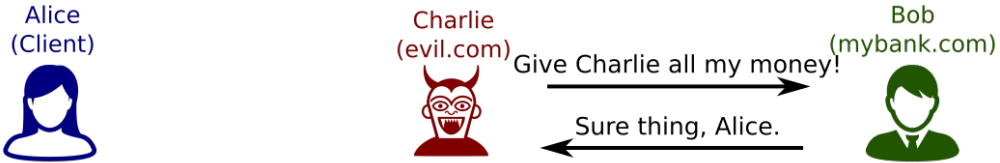

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  "This result motivates and confirms the need to modify the handshake hashes to contain the server Finished when we add post-handshake authentication..."

Attack cause and mitigation

- Attack shows initial proposal for delayed client authentication incomplete.
- Highlights strict necessity of binding client signatures to server certificate.
- Working group proposed to include transcript to bind them to *sessions*.
- This proposal was merged in revision 11, which prevents our attack.

Conclusions

- First comprehensive analysis of the new TLS 1.3 modes and their interaction.
- This story has a happy ending:
  - Revision 10 was successfully verified.
  - Tamarin was used to find an interaction attack on delayed authentication.
  - Proposed fix verified and included in revision 11.
- Future work: Update model and verify revision 13.
- Our work is part of the larger, concerted effort of different approaches to hardening TLS 1.3.

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