Formal security analysis of authentication in an asynchronous communication model

Bsc thesis presentation

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KTH

Outline

Introduction

Topic

- Secure Data Sharing protocol
- Formal analysis tool Tamarin Prover
- Focus on authentication

Relevance of formal security analysis

- More complex systems
- High cost of failure
- Competitive advantage
- Authenticity is key

Objectives

Does the authentication in the Secure Data Sharing protocol satisfy its intended security goals?

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1. Identify key concerns
2. Model the protocol and formulate requirements as lemmas
3. Draw conclusions about the security

Background

Formal verification

1. Create a model of the system
2. Describe the properties to be verified
3. Execute the tool to confirm if properties hold

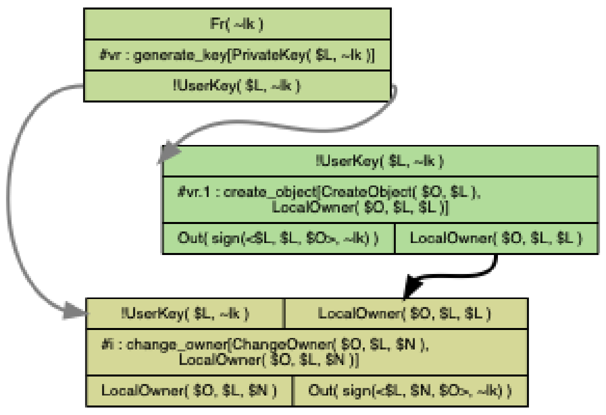
Tamarin Prover introduction

- Verification tool for security protocols
- Developed at ETH Zürich
- Inspired by ProVerif
- Used to analyse 5G authentication and TLSv1.3

Tamarin Prover modeling

- System state is a multiset of facts
- State transitions specified by rewriting system, using rules
- Properties to verify specified by lemmas using temporal logic
- Resulting traces are visualised

Tamarin Prover example



Example trace visualisation showing rules and facts.

Authenticity

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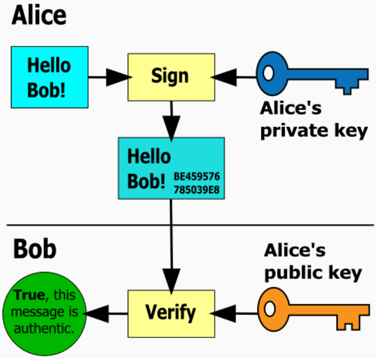
- Authentication = confirming authenticity
- Replay attacks

- Used for authentication
- Asymmetric cryptography
- Encrypt hash of the message



Secure Data Sharing

The SDS protocol

- Proprietary protocol, public security model
- Developed by Stockholm startup
- Not released yet

Protocol goals

- Encrypted data stored on server
- Access control per data item
- Clients participate asynchronously
- Data items kept up to date through notifications

Security requirements

In end-to-end mode:

- Only user's device is trusted
- Confidentiality, integrity, authenticity, authorization
- Untrusted server operator

In basic mode:

- Assume honest server operator

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- We then followed the tutorials in the Tamarin Prover manual to learn the basics.
- As a finishing preparation, we familiarized ourselves with the SDS protocol. We worked with v 0.03 and 0.04

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- Sanity checks - `exists-trace` - lemmas were written.
- Authenticity requirements for each algorithm were identified, and expressed as lemmas.
- Tamarin was used to prove or disprove the lemmas.

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- An object can be shared between users. Different users can have different access levels.
- Each object has one owner, ownership can be transferred with the use of an `owner event`
- Owner events are authenticated with a digital signature. In the analysed version of the protocol, the signature was computed by concatenating the user ids of the current owner, the new owner and the object id.

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- ```
  //In this case, the owner event is self-signed
    [Out(sign(<$L, $L, $O>, ~lk)),
     LocalOwner($O, $L, $L)]
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rule receive_owner:
[!UserKey($PP, ~ppk), !UserKey($P, ~pk),
  In(signature), LocalOwner($O, $L, $PP)]

--[IfTrue(verify(signature, <$PP, $P, $O>, pk(~ppk))),
  LocalOwner($O, $L, $P)]->

[LocalOwner($O, $L, $P)]

rule change_owner:
[!UserKey($L, ~lk), LocalOwner($O, $L, $L)]
--[ChangeOwner($O, $L, $N), LocalOwner($O, $L, $N)]->
[LocalOwner($O, $L, $N), Out(sign(<$L, $N, $O>, ~lk))]
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- `local_owner_is_authentic`: Show that the origin of owner events is authentic.

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  ==> (Ex prev_owner #j. ChangeOwner(obj, prev_owner, owner) @j
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//or the user created the object themselves.
  | (Ex #j. CreateObject(obj, owner) @j & not(#i < #j))"
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- We found that the lemma `local_owner_is_authentic` only provides non-injective agreement.
- This means that the apparent owner at some point actually was the owner, however the signature is not unique per event.
- Because the signature may be reused, it is possible to fake ownership if one was previously the owner of the object through a replay attack (explained next slide).
- A way to remedy this is to make signatures unique for each event. For instance, an incrementing serial number could be added to each signature.

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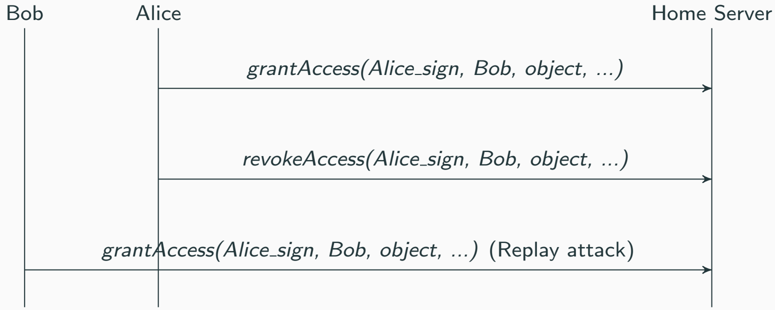

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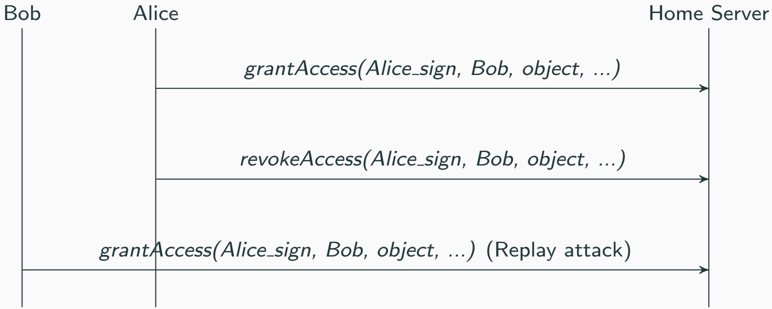

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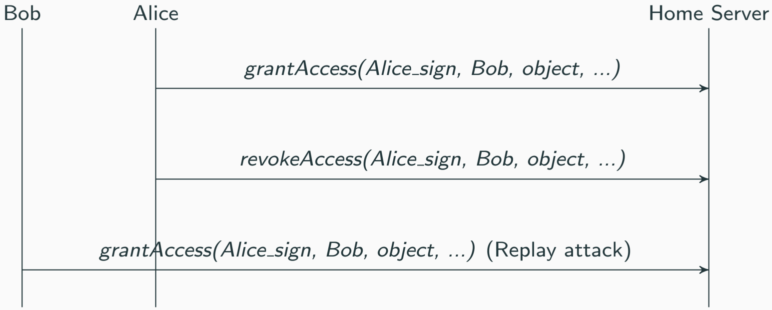

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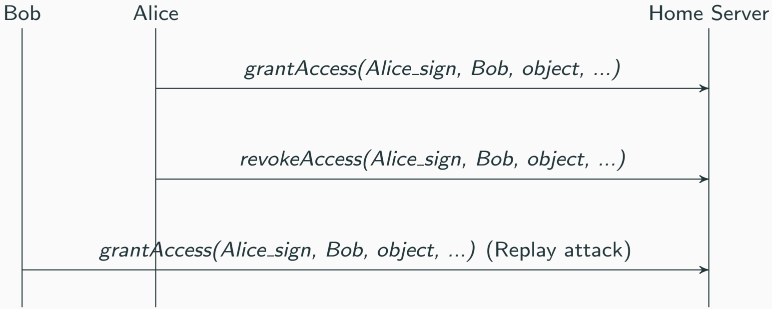

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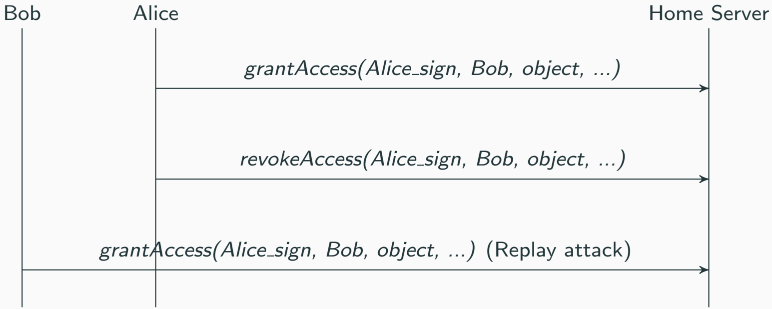

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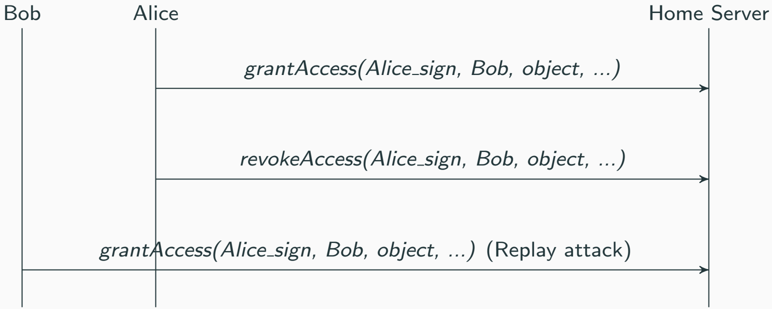

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- Alice wishes to grant some level of access of an object to Bob.
- Alice does this by creating and signing the event *grantAccessEvent* with *Alice_sign*.
- Shortly thereafter, Alice revokes the previously granted access with *revokeAccess*.
- However, Bob copied Alice's signature and uses it to grant himself illegitimate access to the object.

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- In version 0.06 of the protocol, an incrementing number was added to the signature to enforce ordering of owner events and provide stronger authenticity, based on our suggestion.
- Reset events had a similar issue, which was also resolved in the same manner.

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- In version 0.03 the signature was computed over the concatenation of the affected label, the user id of the user making the change, the device number, a counter value, and the list of users and what access level they are granted.

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- The `receive_access_event` rule is then used to receive and verify the event and signature.
- The rule `owner_to_access` acts as a bridge between the access and owner models, it makes sure that the owner is considered to have access as well.

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- This is an authenticity problem because the signature may be reused in the wrong context.
- A user could incorrectly be given authorization to read, modify, or even delete an object which it should not have access to.
- This can be remedied by making the signature in the access event include the object identifier.

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- In version 0.06 of the protocol, the object identifier was added to the signature, based on our suggestion. Therefore, the identified vulnerability no longer exists.

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- In the basic mode, users can register and authenticate with both stateless and stateful devices. Public key cryptography is not used, instead a user's identity is their email address or phone number.
- The purpose of the following procedure is to verify that API requests to the home server originate from the claimed user. The email channel is assumed to be secure.

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- The home server responds by sending a verification link to the specified email address. The link expires within 10 minutes.
- When the user clicks the link, the server can match the URL to the user id, and thus conclude the request to be authentic. In that case, the server returns a session key which is used to authenticate further requests.

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- The additional rules `read_email` and `write_email` were used to test what would happen if the adversary could read or write to the email inbox.
- The rule `reveal_user_email` gives the adversary knowledge of the email address for a given user id.

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- Since the session key is used as a form of authentication in subsequent operations of the protocol, this ensures that authenticity is upheld.

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- Under the assumption that the user's email is secure during the procedure, an attacker cannot gain access to the session key. Thus, authenticity is upheld. This level of security is similar to services with email password reset.

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- The identified issues have been resolved, based on our suggestions.
- Our analysis of the basic mode proved the security of the authentication process, assuming that the user's email is not compromised at the time of authentication. We can thus conclude that it satisfies its intended security goals.

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- Without the terminology and framework of concepts such as the CIA triad and Lowe's hierarchy it is hard to do a relevant analysis.
- Analysis would be easier if all protocol specifications included detailed statements of intended security guarantees.

Future work

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- For a more complete picture of the security of the SDS protocol, additional security aspects should be analysed. The protocol is, apart from authenticity, also intended to provide confidentiality, integrity and authorization. These can all be analysed using the same method as in this report.
- Another direction is to see if this type of analysis can be made easier. For instance, if it is possible to implement the SDS protocol using ProScript or other types of verification tools.

Thanks!

Thank you for listening! Now time for opposition and questions.

Examiner: Panos Papadimitratos

Supervisor: Mohammad Khodaei