Automated Reasoning for Security Protocol Analysis

The ASW Protocol Revisited: A Unified View

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Introduction

- ASW: an asynchronous, optimistic fair exchange protocol introduced by [Asokan, Shoup, Waidner].
  - Such protocols and their objectives are often beyond the scope of existing protocol analysis tools.

- We revisit the analysis of ASW:
  - We adopt a simple, unified view of the protocol that enables us to reason about protocol objectives.
  - We perform an automated analysis for both finite and infinite protocol sessions using two tools, OFMC and OFMC-FP

Protocol Objectives

- Fair exchange: At the end of a protocol execution, either both parties possess valid contracts, or neither does.
- Effectiveness: If two honest agents complete a protocol run and neither chooses to abort it, then both possess a valid contract.
- Timely completion: Both originator and responder can be sure of completion within a finite amount of time.
- Non-repudiability: A contract contains implicit proof of the agents' acceptance of the contractual text.
- Abuse-Freeness: Neither party can prove to an outside verifier that he has the power to decide the outcome of the protocol.

The ASW Protocol (1/3)

Exchange subprotocol:

1. $O \rightarrow R: \quad me_1 = Sig_O(V_O, V_R, T, text, h(N_O))$
2. $R \rightarrow O: \quad me_2 = Sig_R(me_1, h(N_R))$
3. $O \rightarrow R: \quad N_O$
4. $R \rightarrow O: \quad N_R$

- Two rounds: exchange of public commitments followed by exchange of secret commitments
- Upon successful completion, both parties will be in possession of a standard valid contract of the form me_1, me_2, N_O, N_R.

The ASW Protocol (2/3)

Abort subprotocol:

1. $O \to T$: $ma_1 =$ $Sig_O(aborted, me_1)$
2. $T \to O$: $ma_2 =$ if $resolved(me_1)$ then $Sig_T(me_1, me_2)$
   else $Sig_T(aborted, ma_1)$; $aborted(me_1) = true$

- If O does not receive R's reply me_2 "in time", he may initiate the abort subprotocol with the T3P.
- T3P responds with an abort token if me_1 has not been previously resolved. Otherwise, he issues a replacement contract of the form $Sig_T(me_1, me_2)$ and marks me_1 as aborted.
- There are thus two forms of valid contract: *standard* and *replacement*.
- Note that an abort token is not proof that the associated contract is invalid. It merely asserts that the T3P has not and will not issue a replacement contract.

The ASW Protocol (3/3)

Resolve subprotocol:

1. $O \rightarrow T$: $mr_1 =$ me_1, me_2
2. $T \rightarrow O$: $mr_2 =$ if $aborted(me_1)$ then $Sig_T(aborted, ma_1)$
   else $Sig_T(me_1, me_2)$; $resolved(me_1) = true$

- Can be initiated by either O or R if the secret commitment expected is not received in time.

- Analogous to the Abort subprotocol: if me_1 has previously been aborted, the T3P responds with an abort token. Otherwise, he sends a replacement contract and marks me_1 as resolved.

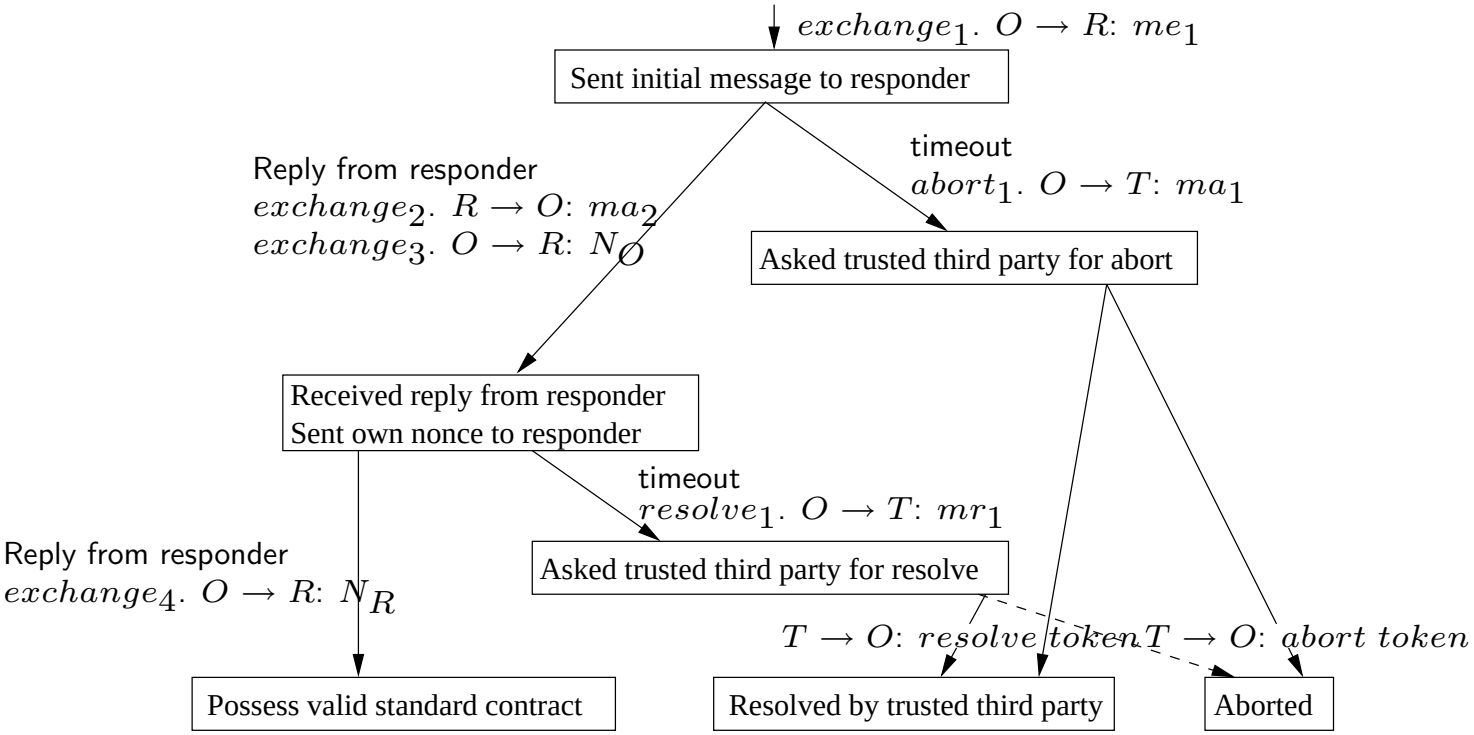
The Unified View (1/3)

- We wish to view and reason about the protocol as a single, unified protocol with alternate execution paths. We view the abort and resolve subprotocols as *part* of the main exchange protocol.

- For instance, the unified originator role is as follows:

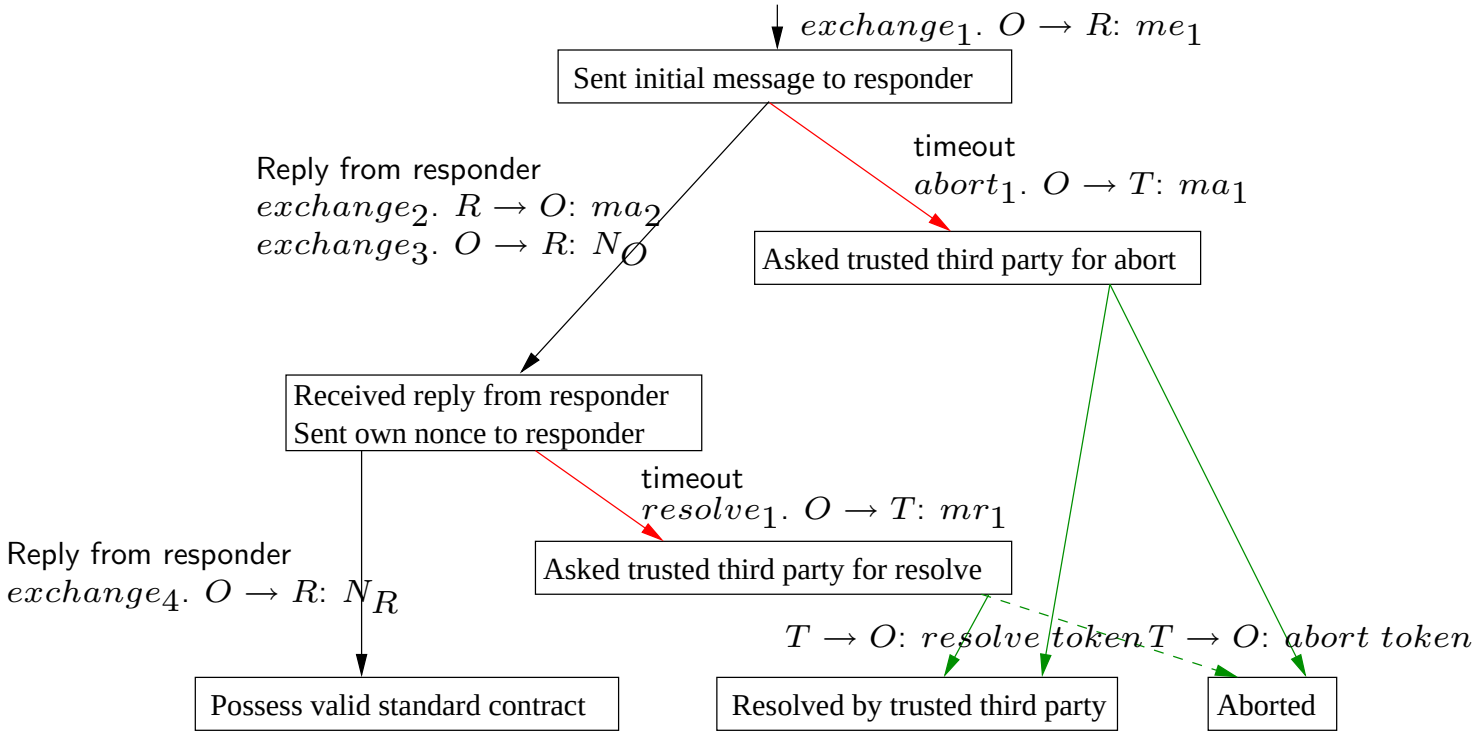
$exchange_1.\ O \rightarrow R:$	me_1
if *timeout* then	$abort_1.\ O \rightarrow T : ma_1$
	$abort_2.\ T \rightarrow O : ma_2$ (*abort token* or *replacement contract*)
else	
$exchange_2.\ R \rightarrow O:$	me_2
$exchange_3.\ O \rightarrow R:$	N_O
if *timeout* then	$resolve_1.\ O \rightarrow T : mr_1$
	$resolve_2.\ T \rightarrow O : mr_2$ (*abort token* or *replacement contract*)
else	
$exchange_4.\ R \rightarrow O:$	N_R

The Unified View (2/3)



- This unified view yields an intuitive agent model. The internal states of an agent playing in the originator role are shown here.

The Unified View (3/3)



- Two fairness constraints: (a) timeout; (b) guaranteed response from the T3P ensure that any honest originator will eventually reach one of the final states.

Reasoning about the Unified View (1/2)

- We wish show that if an honest agent receives an abort token, then no other agent can obtain a valid contract.

- A simple meta-argumentation allows us to formulate protocol objectives as state-reachability problems in an infinite state transition system without fairness constraints:
  - We can ignore intermediate states.
  - We can therefore spare ourselves liveness considerations, e.g. "an agent can eventually reach a certain state".
  - Rather, we check that if an agent reaches his final state, then his interests are ensured.

Reasoning about the Unified View (2/2)

- Like [Shmatikov & Mitchell] and others, we thus encode the protocol objectives as *safety properties* in a transition system without fairness constraints.
- Note that fairness constraints exclude traces; this is therefore a sound abstraction to make.
- The challenge is to find appropriate safety properties.

Encoding the Protocol Objectives

- Certain objectives (e.g. timeliness) can be shown to hold via simple reasoning about the protocol based on the unified view.
- In our analysis, we focus on the following aspect of fair exchange:

  If an honest agent receives an abort token, then nobody (except the T3P) can ever obtain a valid standard or replacement contract.

- This is a standard secrecy property within the scope of most protocol analysis tools.
- We note that we can check that this property is ensured even in sessions with the intruder.

An Attack on This Formulation of Fair Exchange

$e_1.\quad I \to R: \quad me_1$
$e_2.\quad R \to I: \quad me_2$
$e_3.\quad I \to R: \quad N_I$
$e_4.\quad R \to I: \quad N_R$

$a_1.\quad I \to T: \quad ma_1$
$a_2.\quad T \to I: \quad abort\ token$

$e_1'.\quad I \to R: \quad me_1$
$e_2'.\quad R \to I: \quad me_2{}'$
Intruder stops communication

$r_1.\quad R \to T: \quad \{me_1, me_2{}'\}$
$r_2.\quad T \to R: \quad abort\ token$

- OFMC reports the attack shown here, in which it is indeed the case that an honest R receives only an abort token, while the intruder receives a valid contract. Note, however, that R *also* possesses this contract, but received it in a different session.

- A questionable attack, but shows a subtlety of the objectives.

Conclusion

- Using OFMC-FP, we have verified, for infinitely many sessions, that the protocol fulfills a slightly weakened fair exchange objective.
- The unified view gives us a strong basis for reasoning about the protocol.
- This reasoning allows us to reduce several of the protocol's objectives to standard secrecy and authentication goals digestible by standard analysis tools.
- Even with these simplified objectives, their modelling presents several practical challenges.