On the relationship of traditional and Web Services Security protocols

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Traditional security protocols

We identify traditional security protocols with the common notation in the literature in the style of Dolev-Yao in which both the concrete syntax and the concrete cryptographic algorithms are abstracted as constructors of a free algebra.

1. A$\rightarrow$B : $\{n_a, A\}_{PK(B)}$
2. B$\rightarrow$A : $\{n_a, n_b, B\}_{PK(A)}$
3. A$\rightarrow$B : $\{n_b\}_{PK(B)}$

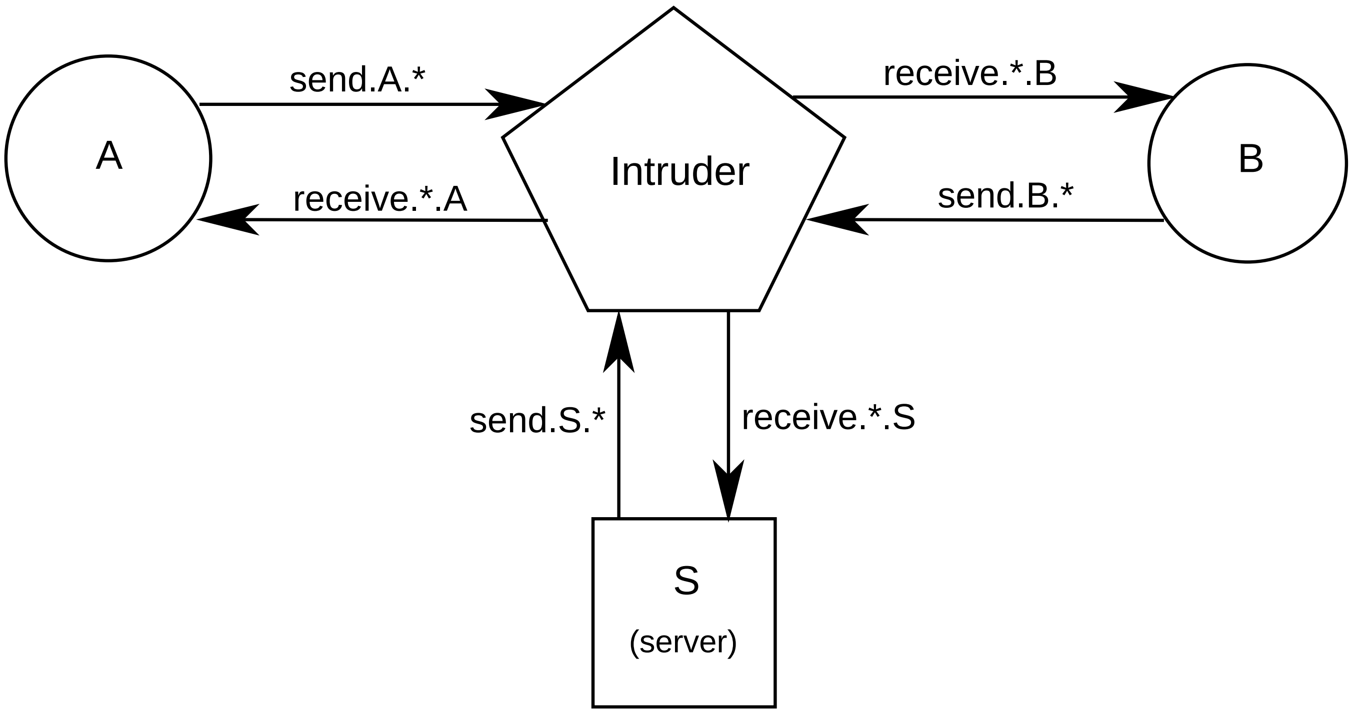
Casper - Compiler for Analysing Security Protocols

Casper adopts this notation as its input.

```
#Protocol description
0.     -> A : B
1.   A -> B : {na, A}{PK(B)}
2.   B -> A : {na, nb, B}{PK(A)}
3.   A -> B : {nb}{PK(B)}
```

Modelling a protocol

$$SYSTEM \mathrel{\widehat{=}} (|||_{A \in Honest} P_A) \parallel INTRUDER(IIK)$$



Web Services Security - Overview

WS-Security was initially proposed by Microsoft in October 2001.

In June 2002 WS-Security was submitted to the Oasis standard body and in March 2004 it became an Oasis Standard.

It defines elements to incorporate security tokens within SOAP messages.

A security token is an XML illustration of a collection of one or more claims.

A claim is a statement made by an entity and can be name, password, identity, key or privileges.

XML-Signature and XML-Encryption are used for achieving integrity and confidentiality of the security tokens.

XML-Signature

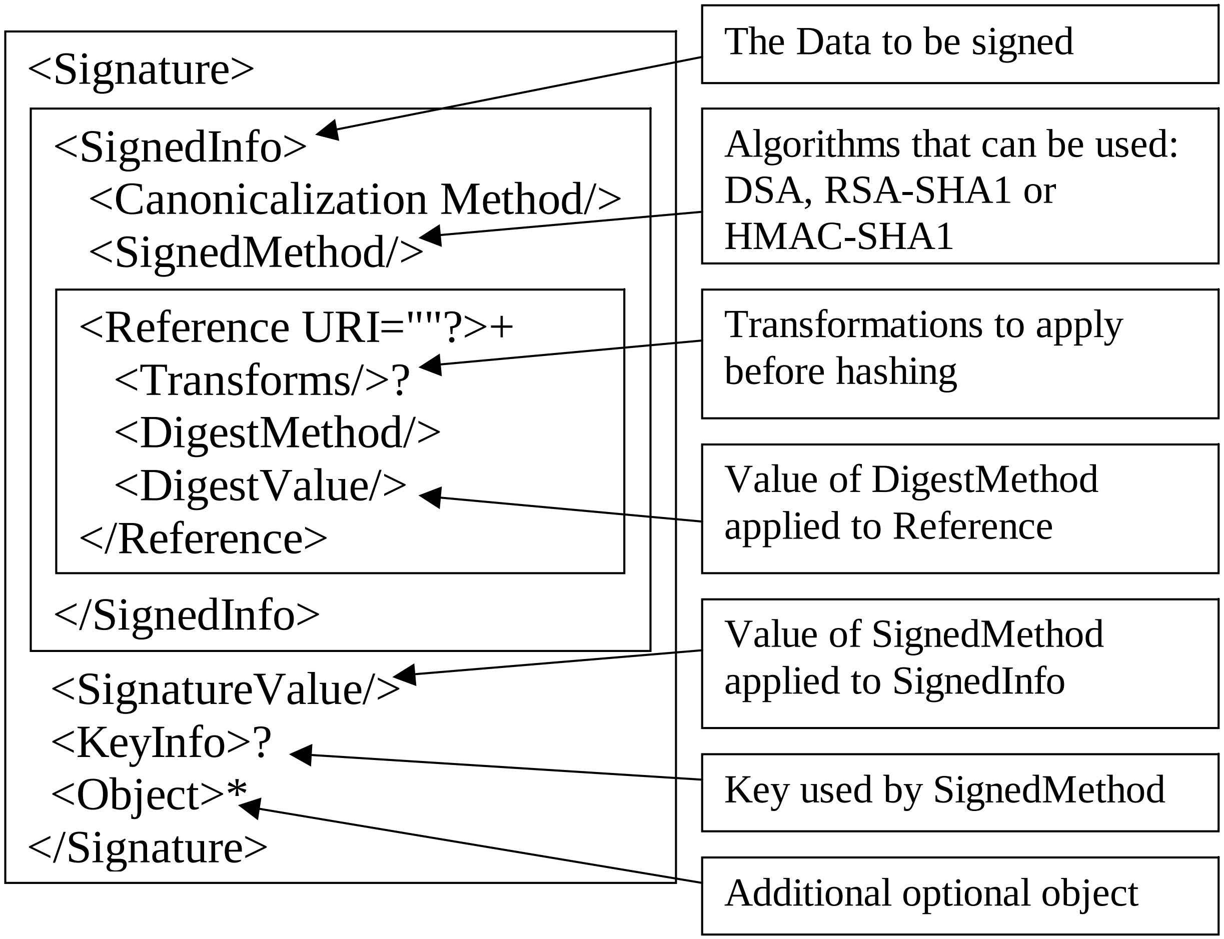


Figure 1: Structure of XML-Signature element

Modelling WS-Security

We construct a mapping ϕ from SOAP messages to Casper input, such that if a WS-security protocol contains the messages $m_1, m_2 ..., m_n$ then,

1. If an attack is found on $\phi(m_1), \phi(m_2)..., \phi(m_n)$ then a corresponding attack can be reproduced on $m_1, m_2..., m_n$.
2. If an attack exists on $m_1, m_2..., m_n$ then it also exists on $\phi(m_1), \phi(m_2)..., \phi(m_n)$. (MFPS05)

More important of the above properties is (2), since we definitely do not want to generate a false "proof" of correctness using the translation.

Any attack found by Casper can be translated back to make sure it is really present in the original protocol.

Message M - taken from an Oasis proposed protocol

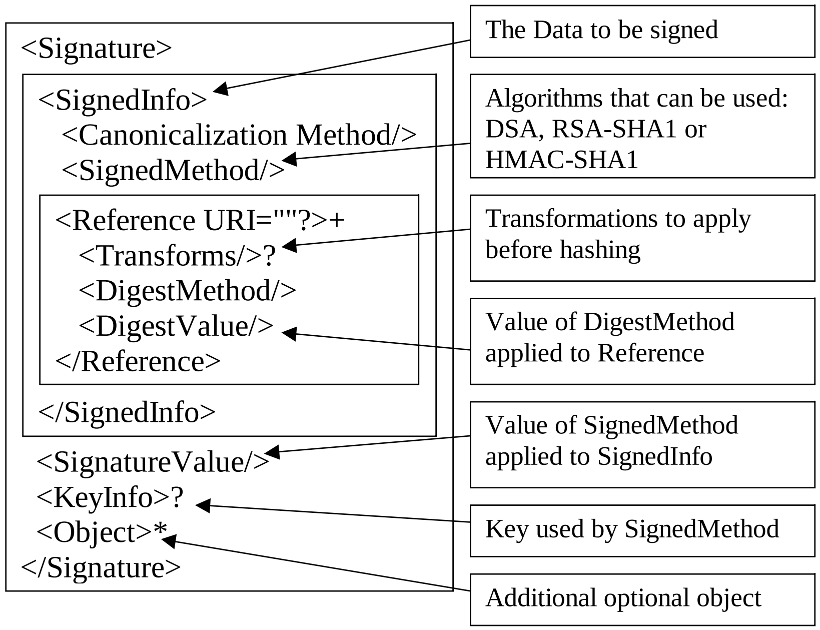
```
<Envelope>
 <Header>
  <Security mustUnderstand="1">
   <BinarySecurityToken ValueType="x509v3" Id="myCert"> BV1
   </BinarySecurityToken>
   <Signature>
    <SignedInfo>
     <CanonicalizationMethod Algorithm=.... />
     <SignatureMethod Algorithm="http://www.w3.org/2000/09/xmldsig\#rsa-sha1"/>
     <Reference URI="#body">
      <Transforms>
       <Transform Algorithm=.... />
      </Transforms>
      <DigestMethod Algorithm=... />
      <DigestValue> BV2 </DigestValue>
     </Reference>
    </SignedInfo>
    <SignatureValue> BV3 </SignatureValue>
    <KeyInfo>
     <SecurityTokenReference>
      <Reference URI="#myCert" />
     </SecurityTokenReference>
    </KeyInfo>
   </Signature>
```

```
      <EncryptedKey>
        <EncryptedMethod Algorithm="http://www.w3.org/2001/04/xmlenc#rsa-1_5"/>
        <KeyInfo>
          <SecurityTokenReference>
            <KeyIdentifier ValueType="X509v3"> BV4
            </KeyIdentifier>
          </SecurityTokenReference>
        </KeyInfo>
        <CipherData>
          <CipherValue> BV5 </CipherValue>
        </CipherData>
        <ReferenceList>
          <DataReference URI="#enc" />
        </ReferenceList>
      </EncryptedKey>
    </Security>
  </Header>
  <Body  Id="body">
    <EncryptedData Id="enc" Type="http://www.w3.org/2001/04/xmlenc#content">
      <EncryptedMethod Algorithm="http://www.w3.org/2001/04/xmlenc#tripledes-cbc" />
      <CipherData>
        <CipherValue> BV6 </CipherValue>
      </CipherData>
    </EncryptedData>
  </Body>
</Envelope>
```

Applying ϕ on `Security` element

$$\phi(\langle Security\rangle ... \langle/Security\rangle) =$$
$$\phi(\langle BinarySecurityToken\rangle ... \langle/BinarySecurityToken\rangle),$$
$$\phi(\langle EncryptedKey\rangle ... \langle/EncryptedKey\rangle), \phi(\langle Signature\rangle ... \langle/Signature\rangle)$$

Applying ϕ on `Signature` element



$$\phi(\langle Signature\rangle ... \langle / Signature\rangle) = \{\phi(\langle Reference ...\rangle ... \langle / Reference\rangle), \ldots$$
$$\phi(\langle Reference ...\rangle ... \langle / Reference\rangle) ...\}_{\phi(\langle KeyInfo\rangle ... \langle / KeyInfo\rangle, SIG)}$$
$$\phi(\langle Reference ...\rangle ... \langle / Reference\rangle), \ldots, \phi(\langle Reference ...\rangle ... \langle / Reference\rangle) ...$$

Demonstrate the complete derivation of $\phi(M)$

$\phi(M)$

$\Rightarrow \phi(\langle\text{Header}\rangle\ldots\langle/\text{Header}\rangle),\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \phi(\langle\text{Security}\rangle\ldots\langle/\text{Security}\rangle),\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \phi(\langle\text{BinarySecurityToken}\rangle\ldots\langle/\text{BinarySecurityToken}\rangle)$, $\phi(\langle\text{EncryptedKey}\rangle\ldots\langle/\text{EncryptedKey}\rangle)$, $\phi(\langle\text{Signature}\rangle\ldots\langle/\text{Signature}\rangle)$, $\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \phi(\langle\text{EncryptedKey}\rangle\ldots\langle/\text{EncryptedKey}\rangle)$, $\phi(\langle\text{Signature}\rangle\ldots\langle/\text{Signature}\rangle)$, $\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \phi(\langle\text{ReferenceList}\rangle\ldots\langle/\text{ReferenceList}\rangle,\{\text{K}\})$, $\{\text{K}\}_{\phi(\langle\text{KeyInfo}\rangle\ldots\langle/\text{KeyInfo}\rangle,\text{ENC})}$, $\phi(\langle\text{Signature}\rangle\ldots\langle/\text{Signature}\rangle)$, $\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \phi(\langle\text{DataReference URI=\#enc }/\rangle,\{\text{K}\})$, $\{\text{K}\}_{\phi(\langle\text{KeyInfo}\rangle\ldots\langle/\text{KeyInfo}\rangle,\text{ENC})}$, $\phi(\langle\text{Signature}\rangle\ldots\langle/\text{Signature}\rangle)$, $\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\})$, $\{\text{K}\}_{\phi(\langle\text{KeyInfo}\rangle\ldots\langle/\text{KeyInfo}\rangle,\text{ENC})}$, $\phi(\langle\text{Signature}\rangle\ldots\langle/\text{Signature}\rangle)$, $\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\})$, $\{\text{K}\}_{\phi(\langle\text{SecurityTokenReference}\rangle\ldots\langle/\text{SecurityTokenReference}\rangle,\text{ENC})}$, $\phi(\langle\text{Signature}\rangle\ldots\langle/\text{Signature}\rangle)$, $\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\})$, $\{\text{K}\}_{\phi(\langle\text{KeyIdentifier}\rangle\ldots\langle/\text{KeyIdentifier}\rangle,\text{ENC})}$, $\phi(\langle\text{Signature}\rangle\ldots\langle/\text{Signature}\rangle)$, $\phi(\langle\text{Body}\rangle\ldots\langle/\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\})$, $\{\text{K}\}_{\text{PK(B)}}$, $\{\phi(\langle\text{Reference URI=\#body}\rangle\ldots\langle/\text{Reference}\rangle)\}$,

$\{\phi(\langle \text{KeyInfo}\rangle ... \langle /\text{KeyInfo}\rangle),\text{SIG}\},\ \phi(\langle \text{Body}\rangle ... \langle /\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\}),\ \{\text{K}\}_{\text{PK(B)}},$
$\{\phi(\langle \text{DigestMethod}.../\rangle)(\phi(\text{body}))\}_{\phi(\langle \text{KeyInfo}\rangle ... \langle /\text{KeyInfo}\rangle,\text{SIG})},\ \phi(\langle \text{Body}\rangle ... \langle /\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\}),\ \{\text{K}\}_{\text{PK(B)}},\ \{\text{sha1}(\phi(\text{body}))\}_{\phi(\langle \text{KeyInfo}\rangle ... \langle /\text{KeyInfo}\rangle,\text{SIG})},$
$\phi(\langle \text{Body}\rangle ... \langle /\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\}),\ \{\text{K}\}_{\text{PK(B)}},$
$\{\text{sha1}(\{\text{Body}\}_{\phi(\langle \text{EncryptedData Id=``enc''}\rangle ... \langle /\text{EncryptedData}\rangle)})\}_{\phi(\langle \text{KeyInfo}\rangle ... \langle /\text{KeyInfo}\rangle,\text{SIG})},$
$\phi(\langle \text{Body}\rangle ... \langle /\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\}),\ \{\text{K}\}_{\text{PK(B)}},\ \{\text{sha1}(\{\text{Body}\}_{\text{K}})\}_{\phi(\langle \text{KeyInfo}\rangle ... \langle /\text{KeyInfo}\rangle,\text{SIG})},$
$\phi(\langle \text{Body}\rangle ... \langle /\text{Body}\rangle)$

$\Rightarrow$
$\text{Context}(\text{enc},\{\text{K}\}),\ \{\text{K}\}_{\text{PK(B)}},$
$\{\text{sha1}(\{\text{Body}\}_{\text{K}})\}_{\phi(\langle \text{SecurityTokenReference}\rangle ... \langle /\text{SecurityTokenReference}\rangle,\text{SIG})},$
$\phi(\langle \text{Body}\rangle ... \langle /\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\}),\ \{\text{K}\}_{\text{PK(B)}},\ \{\text{sha1}(\{\text{Body}\}_{\text{K}})\}_{\phi(\langle \text{Reference URI=\#myCert}.../\rangle,\text{SIG})},$
$\phi(\langle \text{Body}\rangle ... \langle /\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\}),\ \{\text{K}\}_{\text{PK(B)}},\ \{\text{sha1}(\{\text{Body}\}_{\text{K}})\}_{\text{SK(A)}},\ \phi(\langle \text{Body}\rangle ... \langle /\text{Body}\rangle)$

$\Rightarrow \text{Context}(\text{enc},\{\text{K}\}),\ \{\text{K}\}_{\text{PK(B)}},\ \{\text{sha1}(\{\text{Body}\}_{\text{K}})\}_{\text{SK(A)}},\ \{\text{Body}\}_{\text{K}}$

$\Rightarrow \{\text{K}\}_{\text{PK(B)}},\ \{\text{sha1}(\{\text{Body}\}_{\text{K}})\}_{\text{SK(A)}},\ \{\text{Body}\}_{\text{K}}$

Oasis proposed protocol

1. A$\longrightarrow$B: `M`
2. B$\longrightarrow$A: `M'`

After applying ϕ to both of the messages we get the following protocol.

1. MSG 1 .A$\rightarrow$B : $\{K\}_{PK(B)}$, $\{sha1(\{Body\}_K)\}_{SK(A)}$, $\{Body\}_K$
2. MSG 2. B$\rightarrow$A : $\{K2\}_{PK(A)}$, $\{sha1(\{Body2\}_{K2})\}_{SK(B)}$, $\{Body2\}_{K2}$

An attack

Using FDR the following authentication attack was found.

1. MSG 1. $I \rightarrow Bob : \{K\}_{PK(Bob)}, \{sha1(\{Body\}_K)\}_{SK(I)}, \{Body\}_K$
2. MSG 2. $Bob \rightarrow I : \{K2\}_{PK(I)}, \{sha1(\{Body2\}_{K2})\}_{SK(Bob)}, \{Body2\}_{K2}$
3. MSG 1. $Alice \rightarrow I_{Bob} : \{K3\}_{PK(Bob)}, \{sha1(\{Body3\}_{K3})\}_{SK(Alice)}, \{Body3\}_{K3}$
4. MSG 2. $I_{Bob} \rightarrow Alice : \{K2\}_{PK(Alice)}, \{sha1(\{Body2\}_{K2})\}_{SK(Bob)}, \{Body2\}_{K2}$

Contribution and Ramifications

- Any WSS protocol can be analysed in the traditional model after it was transformed by ϕ
- We would like to emphasise that although this proof is based on the theory of CSP, it is valid for any tool regardless to its underlying theory.
- ϕ's input is the SOAP messages of the protocol to be analysed. This fact allows the unprofessional user to analyse complex WSS protocols in a few minutes time.
- It was suggested that ϕ can be used for making the semantics of WSS clearer.

Proof of a WS-SecureConversation based protocol

WS-SecureConversation Background

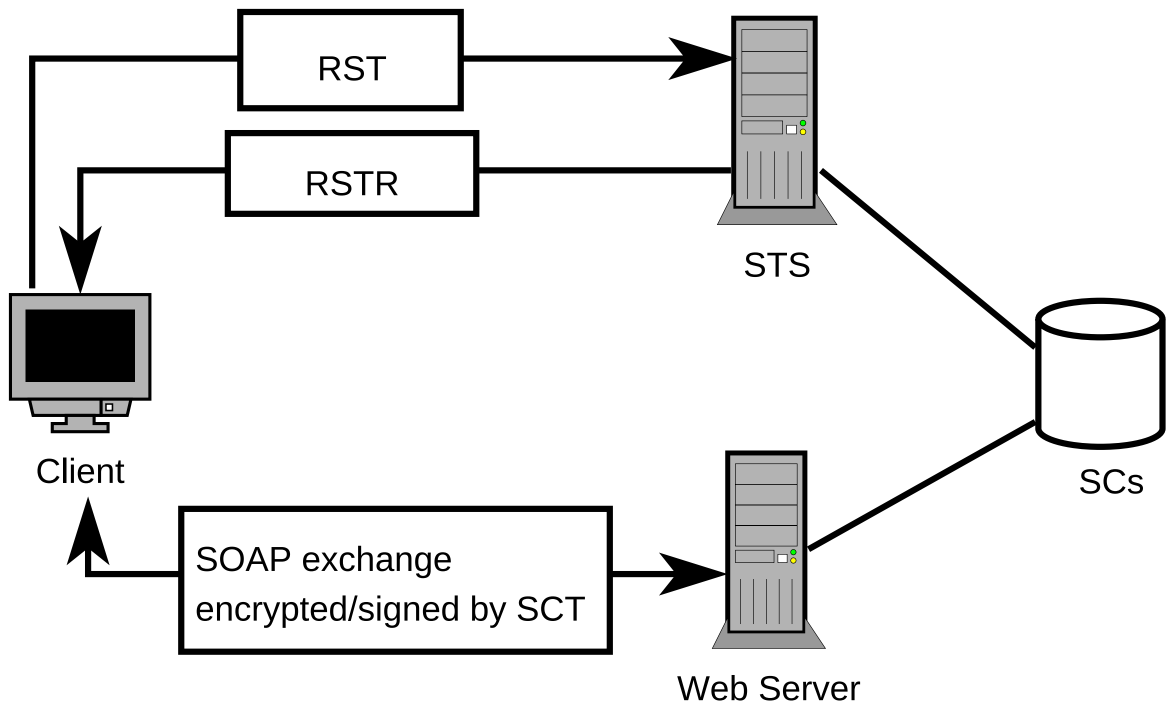
- WS-Security defines security tokens to provide different security properties to the claims that these tokens encapsulate.
- Yet, the process of verifying these tokens against the security policy has to be repeated for each SOAP message.
- WS-SecureConversation addresses this issue. It is built upon WS-Security and WS-Trust to allow a requestor and a Web Service to set up a mutually authenticated *security context*.
- After the *security context* establishment, the parties may use this shared secret with WS-Security for signing and encrypting messages.

Establishing *security context*

WS-Trust defines three ways to establish *security context*

- **Security Context Token is created by a security token service (STS)**
  1. A –> STS : RST (may contain an `Entropy` (e.g. secret key))
  2. STS –> A : RSTR (contains an `Entropy` and `SCT`)

  If MSG 1. includes an `Entropy` then `SCT` $= p\text{–}sha1(k_A, K_{STS})$
  else `SCT` $= K_{STS}$
- **Security Context is created by one of the agents and propagated with a message**
- **Security Context created by negotiation**



Note that WS-SecureConversation and WS-Trust do not define how to secure the `RST`, `RSTR` and `SCT`.

Modelling WS-SecureConversation

1. Extend ϕ to capture the new tokens (e.g. RST, RSTR, SCT etc)
2. Prove by induction that the extension of ϕ does not harm the safety of ϕ

Example - WSE's WS-SecureConversation

The protocol after applied to ϕ:

1. A→B: RST, UMI1, anonymous, B, ts1,
   $\{$sha1(ts1), sha1(SecurityToken-b8...,$\{K_1\}_{PK(B)}$),
   sha1(RST), sha1(UMI1), sha1(anonymous), sha1(B)$\}_{p\text{-}sha1(pass(A),N_A+ts1)}$
   sha1(password(A),N_A,ts1), N_A, ts1,$\{K_1\}_{PK(B)}$
2. B→A: RSTR, UMI2, UMI1, anonymous, ts2,
   $\{$sha1(RSTR), sha1(UMI2), sha1(UMI1), sha1(anonymous),
   (sha1(ts2),sha1(uuid1, ts2', $\{K_2\}_{K_1}$))$\}_{SK(B)}$,uuid1, ts2', $\{K_2\}_{K_1}$
3. A→B: UMI3, anonymous, B, ts3, (uuid1, ts2'), $\{$sha1(UMI3), sha1(anonymous),
   sha1(B), sha1(ts3), sha1(body1)$\}_{p\text{-}sha1(K_1,K_2)}$,$\{$body1$\}_{p\text{-}sha1(K_1,K_2)}$
4. B→A: UMI4, UMI3, A, ts4, (uuid1, ts2'),$\{$sha1(UMI4), sha1(UMI3),
   sha1(anonymous),sha1(ts4),sha1(body2)$\}_{p\text{-}sha1(K_1,K_2)}$,
   $\{$body2$\}_{p\text{-}sha1(K_1,K_2)}$

After applying some simplifying transformations...

MSG 1. A→B: UMI1, $\{$UMI1, B, $\{K_1\}_{PK(B)})\}_{p\text{-}sha1(pass(A),N_A)}$,
sha1(password(A),N_A)), N_A, $\{K_1\}_{PK(B)}$

MSG 2. B→A: $\{$UMI1, UMI2, $\{K_2\}_{K_1}\}_{SK(B)}$,uuid1,$\{K_2\}_{K_1}$

MSG 3. A→B: $\{$UMI3, B, body1$\}_{p\text{-}sha1(K_1,K_2)}$,$\{$body1$\}_{p\text{-}sha1(K_1,K_2)}$

MSG 4. B→A: $\{$UMI3, UMI4, body2$\}_{p\text{-}sha1(K_1,K_2)}$,$\{$body2$\}_{p\text{-}sha1(K_1,K_2)}$

No Secrecy violation was found by FDR

- Therefore the original WSS protocol is correct in term of secrecy

An authentication attack

MSG 1α.	A $\rightarrow$ I_B	: UMI1, {UMI1, B, $\{K_1\}_{PK(B)}$)$\}_{p\text{-}sha1(pass(Alice),N_A)}$, sha1(password(Alice),$N_A$)), N_A, $\{K_1\}_{PK(B)}$
MSG 1β.	I $\rightarrow$ B	: UMI1, {UMI1, B, $\{K_1\}_{PK(B)}$)$\}_{p\text{-}sha1(pass(I),N_A)}$, sha1(password(I),$N_A$)), N_A, $\{K_1\}_{PK(B)}$
MSG 2β.	B $\rightarrow$ I	: {UMI1, UMI2, $\{K_2\}_{K_1}\}_{SK(B)}$,uuid1,$\{K_2\}_{K_1}$
MSG 2α.	I_B $\rightarrow$ A	: {UMI1, UMI2, $\{K_2\}_{K_1}\}_{SK(B)}$,uuid1,$\{K_2\}_{K_1}$
MSG 3α.	A $\rightarrow$ I_B	: {UMI3, B, body1$\}_{p\text{-}sha1(K_1,K_2)}$,{body1$\}_{p\text{-}sha1(K_1,K_2)}$
MSG 3β.	I $\rightarrow$ B	: {UMI3, B, body1$\}_{p\text{-}sha1(K_1,K_2)}$,{body1$\}_{p\text{-}sha1(K_1,K_2)}$
MSG 4β.	B $\rightarrow$ I	: {UMI3, UMI4, body2$\}_{p\text{-}sha1(K_1,K_2)}$,{body2$\}_{p\text{-}sha1(K_1,K_2)}$
MSG 4α.	I_B $\rightarrow$ A	: {UMI3, UMI4, body2$\}_{p\text{-}sha1(K_1,K_2)}$,{body2$\}_{p\text{-}sha1(K_1,K_2)}$

In addition

- UMI1 and N_A are not properly authenticated in the WS-Trust part of the protocol.
- UMI3 and UMI4 are not properly authenticated in the WS-SecureConversation part of the protocol.

Conclusion

- That part of SOAP Message Security which lies outside of any cryptographic operators may be constructed at will by any user, trustworthy or malicious. There is nothing secret about it.
- Since Kerckhoff's Known Design Principle is adopted by most if not all crypto-analysts, the extra information about the structure of the messages given by the XML-tagging is assumed anyway.
- We have already shown in ARS04 that there are some interesting ways in which SOAP can assist security by providing degree of protection against type flaw attacks.

Related work

- Gordon and Pucella proposed a security abstraction to RPC services in which requests and responses are encoded as SOAP messages. This abstraction is modelled using an object calculus which its semantics is defined by pi-calculus. This approach is currently limited to checking authentication properties.
- Bhargavan, Fournet, Gordon and Pucella developed a tool (`TulaFale`) based on the Blanchet's `ProVerif`. The tool compiles a description of SOAP-based security protocol and its properties into the pi-calculus and then runs `ProVerif` to analyse it.
- TulaFale specification language was extended for modelling WS-Trust and WS-SecureConversation based protocols.

Future work

1. We have already automated ϕ, we intend to write a user interface for analysing WS-Security protocols.

2. We are interested in “internalising” potential intermediaries and believe we then be able to model and check protocols with arbitrary number of intermediaries.