

Safely composing security protocols via tagging

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→ joint work with Véronique Cortier, Jérémie Delaitre, Myrto Arapinis and Steve Kremer



Cryptographic protocols

- small programs designed to **secure** communication (e.g. secrecy)
- use **cryptographic primitives** (e.g. encryption, signature,)



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The network is unsecure!

Communications take place over a **public** network like the Internet.

Cryptographic protocols (symbolic approach)

Messages are abstracted by terms

- pairing $\langle m_1, m_2 \rangle$,
- symmetric $enc(m, k)$ and public key encryption $enca(m, pub(A))$,
- signature $sign(m, priv(A))$.

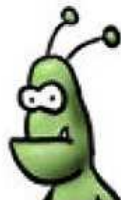
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Presence of an idealized attacker

- may **read**, **intercept** and **send** messages,
- may **build** new messages following **deduction rules** (symbolic manipulation on terms).



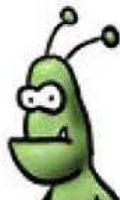
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Examples:

$$\frac{m \quad k}{\text{enc}(m, k)}$$

$$\frac{\text{enc}(m, k) \quad k}{m}$$

$$\frac{\text{enca}(m, \text{pub}(a)) \quad \text{priv}(a)}{m}$$

Formal verification of security protocols

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Example:

$$P_1 : A \rightarrow B : \text{enca}(s, \text{pub}(B)) \quad P_2 : \begin{array}{l} A \rightarrow B : \text{enca}(N_a, \text{pub}(B)) \\ B \rightarrow A : N_a \end{array}$$

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Our goal

investigate **sufficient conditions** to ensure that protocols can be safely used in an environment where:

- 1 other sessions of the **same protocol** may be executed;
- 2 other sessions of **another protocol** may be executed as well.

→ protocols may share identities and keys (e.g. public keys, long-term symmetric keys)

Outline of the talk

- 1 Introduction
- 2 Composition result I: “from one session to many”
- 3 Composition result II: “from one protocol to many”
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compose **different sessions** from the **same** protocol

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Solution

- a **transformation** which maps a protocol P that is secure for a **single session** to a protocol \overline{P} that is secure for an **unbounded number of sessions**.
- **side-effect**: an effective strategy to design secure protocols

Our transformation

Let P be a protocol with ℓ participants as given below:

$$\begin{array}{l} A_{i_1} \rightarrow A_{j_1} : m_1 \\ A_{i_2} \rightarrow A_{j_2} : m_2 \\ \vdots \\ A_{i_k} \rightarrow A_{j_k} : m_k \end{array}$$

Our transformation

The protocol \overline{P} (with ℓ participants) is described below:

Initialisation phase: broadcast of fresh nonces

$$A_1 \rightarrow All : A_1, N_1$$

$$A_2 \rightarrow All : A_2, N_2$$

\vdots

$$A_\ell \rightarrow All : A_\ell, N_\ell$$

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Every participant obtain a **tag** = $\langle A_1, N_1, A_2, N_2, \dots, A_\ell, N_\ell \rangle$

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Main phase:

where the function \overline{m} is defined by:

$$A_{i_1} \rightarrow A_{j_1} : \overline{m_1}$$

$$A_{i_2} \rightarrow A_{j_2} : \overline{m_2}$$

\vdots

$$A_{i_k} \rightarrow A_{j_k} : \overline{m_k}$$

$$\left\{ \begin{array}{ll} \overline{\langle u_1, u_2 \rangle} & \rightarrow \langle \overline{u_1}, \overline{u_2} \rangle \\ \overline{f(u_1, u_2)} & \rightarrow f(\langle \text{tag}, \overline{u_1} \rangle, \overline{u_2}) \\ & \text{when } f \in \{\text{enc}, \text{enca}, \text{sign}\} \\ \overline{u} & \rightarrow u \quad \text{otherwise} \end{array} \right.$$

Composition result “from one session to many”

Theorem

Let P be a protocol with no **critical long-term keys** in plaintext position.

If P preserves the secrecy of s for a **single honest session** of each role then \overline{P} preserves the secrecy of s for an **unbounded number of sessions**.

- **critical long-term keys** do not appear in plaintext
 - this can be easily checked on the finite specification of the protocol
 - often satisfied since it is considered as a prudent practice
- **single honest session** of each role
 - i.e. one an instance of each role (in general 2 or 3);
 - participants engaged in this session are honest.

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Exemple: Needham-Schroeder public key protocol

→ the Lowe’s famous man-in-the-middle attack is prevented

Computational models

Several compilers already exist in the area of cryptographic design, e.g.

- *Scalable protocols for authenticated group key exchange*

[Katz & Yung, 03]

Symbolic models

- *Synthesizing secure protocols*

[Cortier et al., 07]

- *How to guarantee secrecy for cryptographic protocols*

[Beauquier & Gauche, 07]

→ the transformations make **heavy use of cryptography**

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we propose **sufficient** and rather tight **conditions** for a protocol to be **safely** used in an environment where other protocols may be executed as well;

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Example: (given in introduction)

$$P_1 : A \rightarrow B : \text{enca}(s, \text{pub}(B)) \quad P_2 : A \rightarrow B : \text{enca}(N_a, \text{pub}(B)) \\ B \rightarrow A : N_a$$

→ protocols may share identities and keys (*e.g.* public keys, long-term symmetric keys)

Main condition - Tagging

Well-tagged protocol

Each protocol is given an **identifier** (e.g. the protocol's name). This identifier has to appear in any **encrypted** and **signed** message.

→ this **tagging policy** will avoid interaction between two different protocols.

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Example: P_1 is 1-tagged whereas P_2 is 2-tagged

Protocol P_1

$A \rightarrow B : \text{enca}(\langle 1, s \rangle, \text{pub}(B))$

Protocol P_2

$A \rightarrow B : \text{enca}(\langle 2, N_a \rangle, \text{pub}(B))$

$B \rightarrow A : N_a$

Composition result “from one protocol to many”

Theorem

Let P_1 and P_2 be two *well-tagged* protocols such that

- no critical long-term keys appear in plaintext position neither in P_1 nor in P_2 ,
- P_1 is α -tagged and P_2 is β -tagged with $\alpha \neq \beta$.

If P_1 preserves the secrecy of s then $P_1 \mid P_2$ preserves the secrecy of s .

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Extensions that have been already done:

- 1 well-tagged condition can be relaxed: **disjoint encryption** is actually sufficient;
- 2 composition result holds for a **class of security properties** (secrecy, authentication, ...)

The **idea** of adding an identifier is **not novel**:

Principle 10 in the prudent engineering paper

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There are also some formal results about this problem:

- *Protocol independence through disjoint encryption*

[Guttman & Thayer, 00]

→ their condition has to hold on any **valid execution** of the protocol

- *Sufficient conditions for composing security protocols*

[Andova et al., 07]

→ they have to assume **typing hypothesis**, they can not deal with protocols with **ciphertext forwarding**

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Two composition results

- ① one that is useful to compose sessions coming from the same protocol
→ this can be obtained with **dynamic tags**
 - ② one that can be used to compose protocols that satisfy disjoint encryption
→ this can be obtained with **static tags**
- to combine both results, use $\text{tag} = \langle id_\alpha, A_1, N_1, \dots, A_\ell, N_\ell \rangle$.

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Future Work

- obtain a more fine-grained **characterization of a decidable class** (for an unbounded number of sessions and a class security properties)
- other kind of security properties (e.g. equivalence-based properties)
- other kind of composition (e.g. sequence)