A Generic Security API for Symmetric Key Management on Cryptographic Devices

Véronique Cortier and Graham Steel
LORIA, Nancy (France) LSV, Cachan (France)

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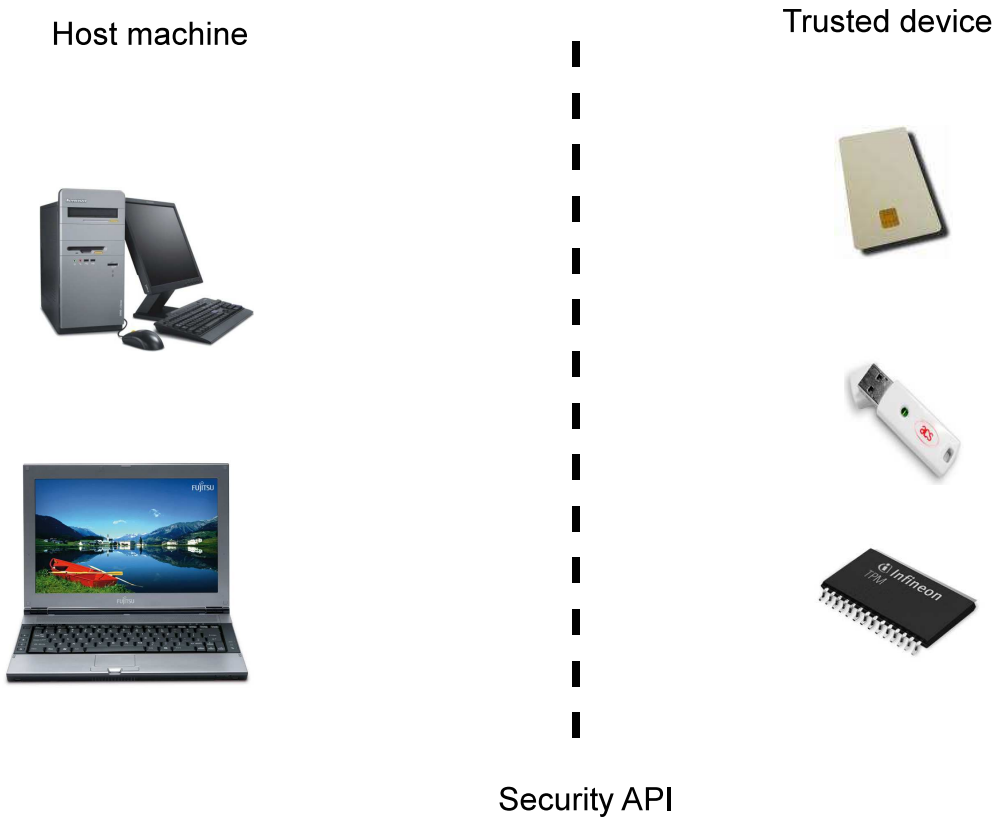
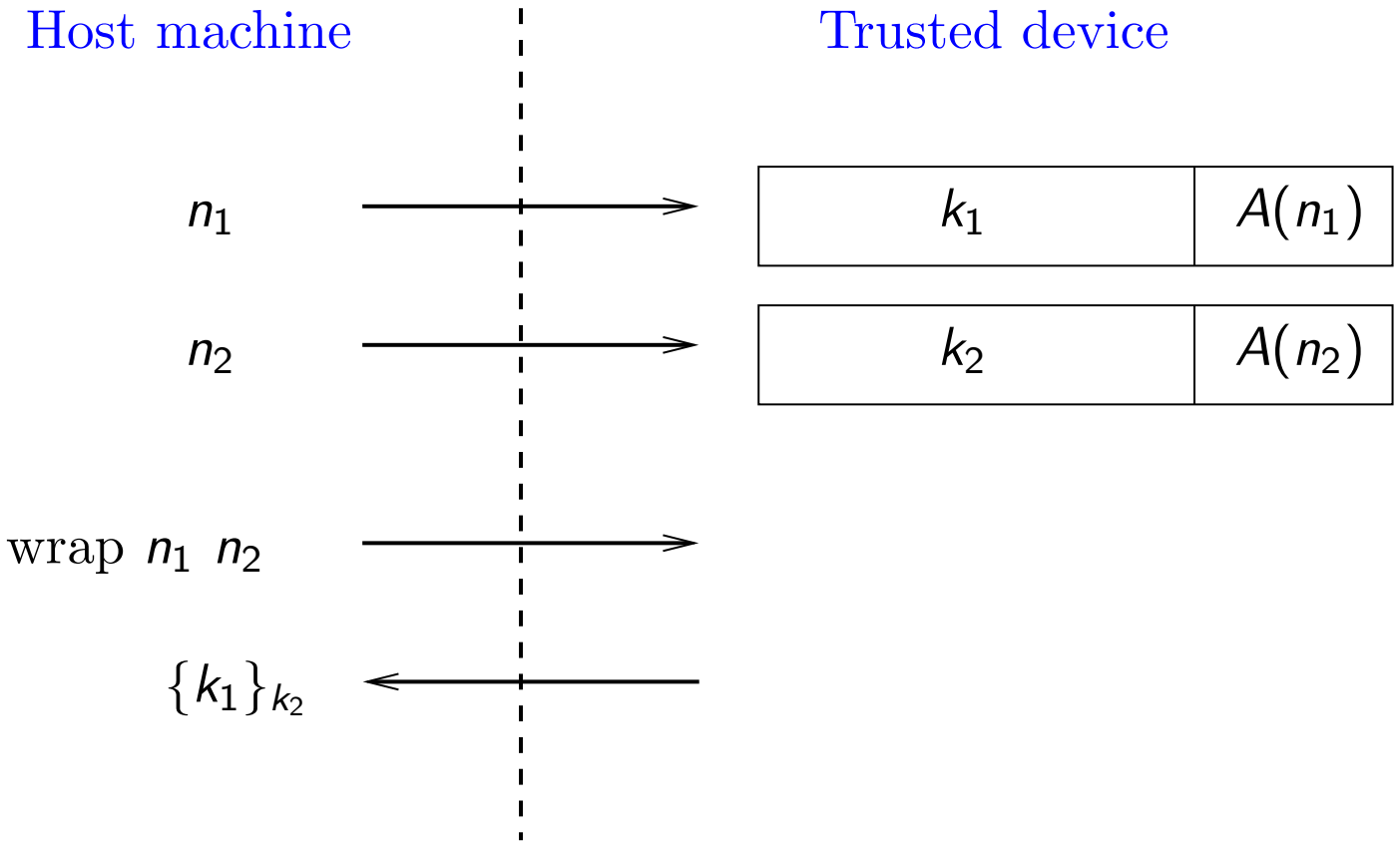
Security APIs



Goal : Enforce security of data stored inside the trusted device, even when connected to untrusted host machines.

Example : PKCS#11



Key Separation Attack (Clulow, 2003)

Intruder knows : $h(n_1, k_1)$, $h(n_2, k_2)$.

State : $\text{wrap}(n_2)$, $\text{decrypt}(n_2)$, $\text{sensitive}(n_1)$, $\text{extract}(n_1)$

Wrap : $h(n_2, k_2)$, $h(n_1, k_1) \rightarrow \{k_1\}_{k_2}$

Decrypt : $h(n_2, k_2)$, $\{k_1\}_{k_2} \rightarrow k_1$

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- Many variations of this attack exist, not easy to fix.
- Data are not related to identities.

Implementing protocols

Security APIs are used to implement endpoints of protocols

Idea :

- Abduct security API policy from suite of protocols it is supposed to implement
- Design generic API that can be instantiated to any protocol
- Prove properties for the generic API that hold no matter what protocol is implemented

Outline of the talk

Generic API : Concepts

Handles for objects stored on device

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N : value of the handle for K

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0. Public data (exists outside device)
1. Secret on device, not usable as key
2. Short term (session) key
3. Long term (key transport) key

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S : Agent identifiers that specify part of the policy

$\longrightarrow$ Crucial for supporting compromised parties

Generic API : Generate Commands

$$\stackrel{N,K}{\Rightarrow} K_a(h_a^g(N, K, i, S)) \quad i \geq 1 \qquad \textbf{(Secure Generate)}$$

$$\stackrel{N,K}{\Rightarrow} K_a(K), K_a(h_a^g(N, K, 0, \mathsf{All})) \qquad \textbf{(Public Generate)}$$

where

- K_a local knowledge on the machine/agent a
- $N \in \mathsf{VarNonce}$,
- $K \in \mathsf{VarNonce}$ if $i = 1$,
- $K \in \mathsf{VarKey}$ if $i = 2$.

Generic API : Encrypt

$$K_a(h_a^{\alpha}(X, K, i_0, S_0)), K_a(x_1), \ldots, K_a(x_k),$$
$$K_a(h_a^{\alpha_1}(X_{n_1}, y_1, i_1, S_1)), \ldots, K_a(h_a^{\alpha_l}(X_{n_l}, y_l, i_l, S_l))$$
$$\Rightarrow K_a(\{x_1, 0, \ldots, x_k, 0, y_1, i_1, S_1, \ldots, y_l, i_l, S_l\}_K) \quad \textbf{(Encrypt)}$$

Require

- $i_0 > i_j$ (keys only encrypt data of strictly lower security level)
- $S_0 \subseteq S_j$

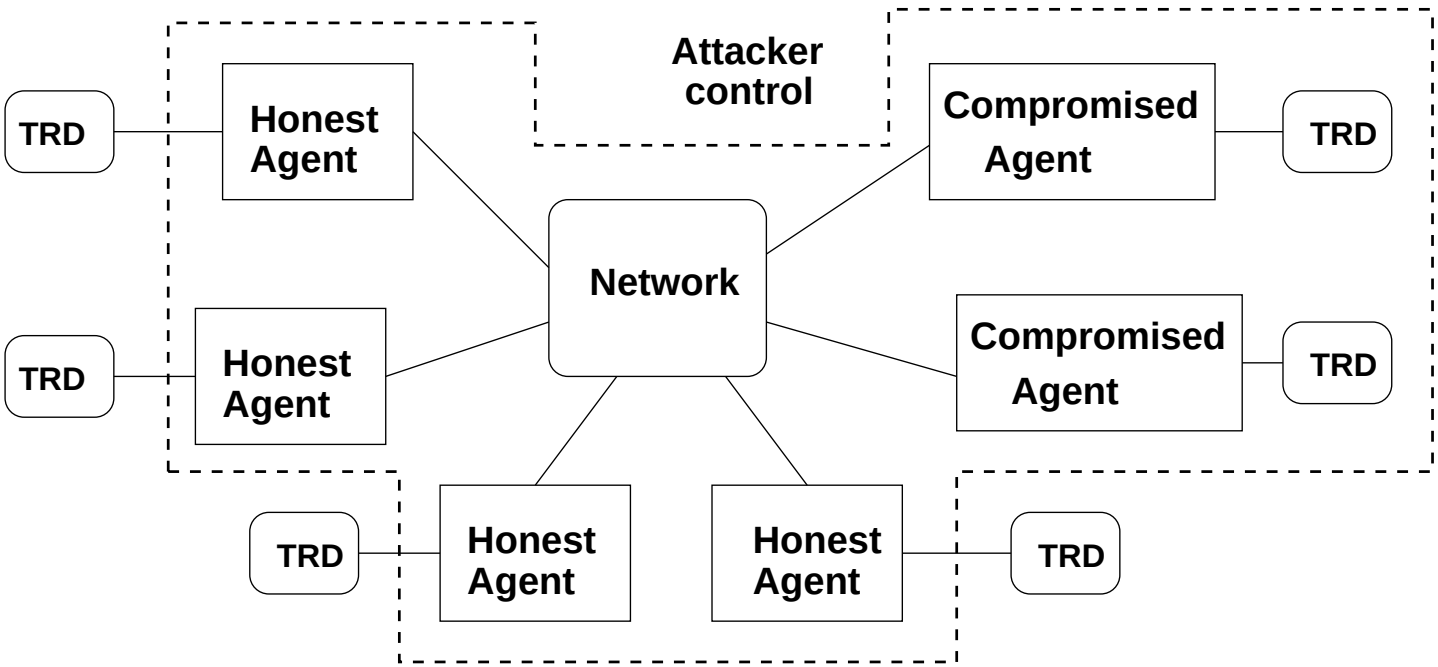
Generic API : Decrypt

$$K_a(h_a^{\alpha}(X, K, i_0, S_0)), K_a(\{x_1, 0, \ldots, x_k, 0, y_1, i_1, S_1, \ldots, y_l, i_l, S_l\}_K),$$
$$K_a(h_a^g(X_1, x_1, 0, \mathsf{All})), \ldots, K_a(h_a^g(X_s, x_s, 0, \mathsf{All})),$$
$$K_a(h_a^g(Y_1, y_1, i_1, S_1)), \ldots, K_a(h_a^g(Y_l, y_l, i_l, S_l))$$
$$\stackrel{N_{r+1},\ldots,N_l}{\Rightarrow} K_a(x_{s+1}) \ldots, K_a(x_k),$$
$$K_a(h^r(N_{r+1}, y_{r+1}, i_{r+1}, S_{r+1})) \ldots, K_a(N_l, y_l, i_l, S_l)$$
(Decrypt/Test)

provided

- $i_0 > i_j$ (keys only encrypt data of strictly lower security level)
- $S_0 \subseteq S_j$ Secure data will be accessible at most to agents in S, which are all authorized agents.

Attacker scenario



Attacker model

As usual, the attacker can apply cryptographic primitives.

$$
\begin{aligned}
K_{\text{int}}(x), K_{\text{int}}(y) &\Rightarrow K_{\text{int}}(\langle x, y \rangle) \\
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$$

The attacker also controls any host machine (incl. honest ones).

$$
\begin{aligned}
K_a(x) &\Rightarrow I(x) \\
I(x) &\Rightarrow K_a(x) \\
K_b(h_b^{\alpha}(x, y, i, S)) &\Rightarrow I(y) \qquad \text{if } b \text{ compromised}
\end{aligned}
$$

Property 1 : Secrecy Invariant

"Secret data of honest users should not be known to the intruder."

i.e. data values k for which there are handles of the form $h_a^\alpha(n, k, i, S)$, where S is a subset of honest users, are unknown to the intruder.

$$\forall a \in \text{Agent}, \forall x, y \in \text{Msg}, \forall i \in \{1,2,3\}, \forall \alpha \in \{r, g\}, \forall S \subseteq H$$
$$\mathcal{S} \vdash h_a^\alpha(x, y, i, S) \Rightarrow \mathcal{S} \not\vdash y \quad \textbf{(Sec)}$$

Theorem

Sec is preserved by application of any of the API commands.

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Limitation : This does not guaranty any security in case some honest keys get compromised (e.g. using brute force attack).

Compromised keys

Assume the adversary has compromised some key K associated to some handle $h(N, K, 2, S)$ with S set of honest agents.

Consider $h(N', K', 1, S')$ with S' honest, $S \subseteq S'$

$$\text{Encrypt} \quad h(N, K, 2, S) \quad h(N', K', 1, S') \Rightarrow \{K'\}_K$$

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$$\text{Encrypt} \quad h(N, K, 2, S) \quad h(N', K', 1, S') \Rightarrow \{K'\}_K$$

$\longrightarrow$ The adversary can get any data of lower security level !

$\Rightarrow$ Short term keys should be regularly erased from the trusted device :

- They are short keys anyway
- Necessary to save the memory of the device

Freshness tests

Erasing compromised keys does not suffice !

Assume the adversary has compromised some key K associated to some (erased) handle $h(N, K, 2, S)$ with S set of honest agents.

And assume the adversary has seen $\{\ldots, K, 2, S, \ldots\}_{K_{ab}}$

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Decrypt $h(N', K_{ab}, 3, S')$ $\{\ldots, K, 2, S, \ldots\}_{K_{ab}} \Rightarrow h(N'', K, 2, S)$

And we are back to the previous case...

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$\Rightarrow$ The token needs to perform some freshness tests.

Property 2 : Secrecy After Compromise

- Intruder may learn some session keys
- Honest users erase old handles
- API enforces tests - no session keys accepted without a test

Theorem

Sec is still preserved.

Implementing protocols

1. Our API can implement all symmetric key management protocols of the Clark & Jacob library.
2. More generally, most of the protocols can be implemented provided that :
   - They are secure !
   - In case of nested encryption, nested cyphertext do not need to be secret.
   - Symmetric key protocols only

Benchmark

Protocol (section in Clark-Jacob)	API	API^r
Needham-Schroeder SK (6.3.1)	+	-
NSSK amended version (6.3.4)	+	+
Otway-Rees (6.3.3)	+	+
Yahalom (6.3.6)	+	-
Carlsen (6.3.7)	+	+
Woo-Lam Mutual Auth (6.3.11)	+	+

`http://www.lsv.ens-cachan.fr/~steel/genericapi/`

Related Work

Cachin and Tandran, presented at CSF'09 (on Wednesday 9th)

- Cryptographic model
- Symmetric and asymmetric encryption, key derivation
- But assume a unique token, having a global view of the system

Further Work

- Cryptographic soundness
- Long-term key update
- PKI (asymmetric crypto, certificates,...)
- Timestamps