The Long and Winding Path to Secure Implementation of GlobalPlatform SCP10

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Overview

• Context
• Deterministic RSA Padding
• Padding Oracle
• Key Reuse
• Secure Implementation
• Conclusion
Context
The smart card world
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[Diagram showing various smart cards and their connections]
SCP (Secure Communication Protocol)

- Establish a secure session between a card and an Off-Card Entity
- 2-steps protocol: Key Exchange + Communication
- SCP10 relies on a Public Key Infrastructure:
  - Both the card and off-card entity have a key pair
  - They use each other public key to encrypt/verify messages
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Key Exchange Modes

(a) Key Transport mode
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(a) Key Transport mode

(b) Key Agreement mode
Our contributions:

1. Abuse blurs and flaws in the RSA encryption in Key Transport
2. Recovered session keys by two independent means
   - In less than a second with the first attack
   - In an average of 2h30 for the second
3. Exploit a design flaw to forge a certificate, signed by the card
4. Implement a (semi-)compliant version of SCP10 as an applet
5. Propose a secure implementation, with an estimation of the corresponding overhead
Our contributions:

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However, we did **not**:

- Attack real cards (no implementation in the wild)
- Try to exploit weakness in the symmetric encryption
Our Threat Model

Our attackers can:

✓ Initiate an SCP10 session with a card
✓ Intercept, read and modify plaintext message transmitted between a legitimate Off-Card Entity and the card
✓ Measure the time needed by the card to respond

They cannot:

× Have physical access to the card
× Break the cryptographic primitives
Deterministic RSA Padding
Perform Security Operation APDU:

\[
M: \underbrace{\text{params}}_{3 \text{ bytes}} \ || \ \underbrace{\text{CRT}}_{[22,42] \text{ bytes}} \ [ || \ \text{CRT} \ ...]
\]
Perform Security Operation APDU:

M: \( \text{params} \ | | \ CRT \ [ | | \ CRT \ldots] \)

\(3 \text{ bytes} \ \ | | \ [22,42] \text{ bytes}\)

CRT: \( \text{header} \ | | \ \text{key} \ [ | | \ 91 \ 08 \ \text{iv} ] \)

\([6,8] \text{ fixed bytes} \ \ | | \ [16,24] \text{ bytes} \ \ | | \ 8 \text{ bytes}\)
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\[
\begin{align*}
\text{EM: 0002} & \| \text{FF..FF} \| 00 \| M \\
& 128-\text{len}(M)-3 \text{ bytes}
\end{align*}
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\[\rightarrow \text{Hybrid padding (mixing EME and EMSA)}\]
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→ Hybrid padding (mixing EME and EMSA)

⇒ Only few unknown bytes (compared to the modulus size)
Coppersmith’s Low Exponent Attack

Recover the message if the unknown part is small enough: we need \( x \leq n^{\frac{1}{e}} \)

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1. European Payments Council. Guidelines on cryptographic algorithms usage and key management. epc342-08, 2018
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Assuming the card is using:

- A 1024 bits modulus
- A small public exponent\(^1\) \((e = 3)\)

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Recover the message if the unknown part is small enough: we need $x \leq n^{\frac{1}{e}}$

Assuming the card is using:

- A 1024 bits modulus
- A small public exponent $^1(e = 3)$

We can recover up to $\left\lfloor \log_2(n^{\frac{1}{3}}) \right\rfloor = 341$ bits ($\approx 42$ bytes)

- An encryption key: 16-24 unknown bytes
- An integrity key (with IV): 26-34 unknown bytes

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In practice...

- Recover the message in 0.35s on average for a 128 bits key
  ⇒ on-the-fly attack possible
- Passive interception only
- Only works for Key Transport
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⚠ Bigger RSA modulus makes the attack easier

⚠ "Classic" PKCS#1v1.5 padding may not be a valid solution...
Padding Oracle
Bleichenbacher’s attack

Abusing **Perform Security Operation**:

- Anybody can send this APDU (no authentication before)
Bleichenbacher’s attack

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- 3 steps on card: decryption $\rightarrow$ verification $\rightarrow$ TLV parsing

![Diagram of the process](image-url)
Bleichenbacher’s attack

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- Unique error code but no mention of constant time
Bleichenbacher’s attack

Abusing **Perform Security Operation**:

- Anybody can send this APDU (no authentication before)
- 3 steps on card: decryption → verification → TLV parsing
- Unique error code but no mention of constant time
- Constant time verification is hard, even harder with TLV parsing
In practice...

- Attack possible with some additional analysis
- Large number of query needed
  - Average: 28000 queries ≈ 2h30
  - Can be reduced by increasing brute force
- No on-the-fly attack: message collection for future decryption

⇒ Need robust RSA padding (OAEP would solve both problems)
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Key Reuse
RSA Key Reuse

Design flaw:

- Same RSA key for Key Transport and Key Agreement
- Same RSA key for confidentiality and authentication

⇒ Less storage, processing and complexity but no key isolation

Consequences:

- Valid signature forgery using Bleichenbacher’s attack
  - On average 74838 queries ≈ 7h
- Certificate forgery, signed by the card
  ⇒ card impersonation in all future sessions
- In case of shared CA, a single forgery may allow impersonating on a large scale
  ⇒ Need key isolation
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⇒ Need key isolation
Secure Implementation
Major countermeasures

- Key isolation
  - Significant overhead during certificate verification
  - No need to repeat it at each session
- RSA-OAEP
  - Negligible overhead ($\approx 0.01s$)
- Enforce public exponent $e = 65537$
  - Negligible overhead
  - Not mandatory when using OAEP
Conclusion
Sum-up

- We tried to apply well known attack to the smart cards world
- Successfully performed two attacks speculating on the implementation
  - We believe our assumption to be reasonable giving past attacks
  - Key isolation is not implementation dependent
- Suggest mitigations:
  - Easy to add in the specification
  - Reasonable overhead
- GlobalPlatform released a new standard version based on our recommendations
Thank you for your attention!