The Long and Winding Path to Secure Implementation of GlobalPlatform SCP10

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Context

The smart card world

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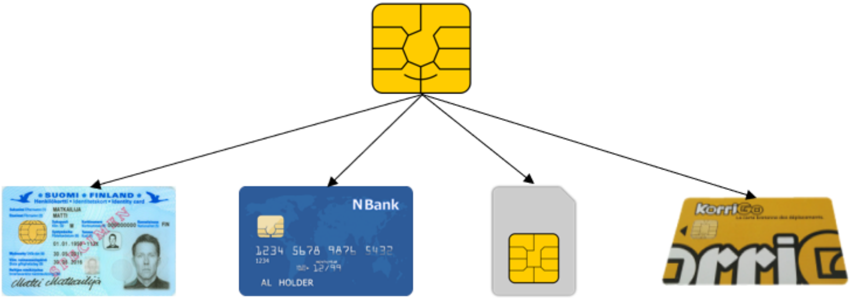
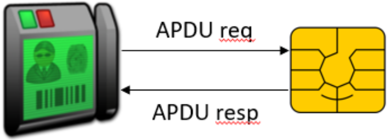


SCP (Secure Communication Protocol)



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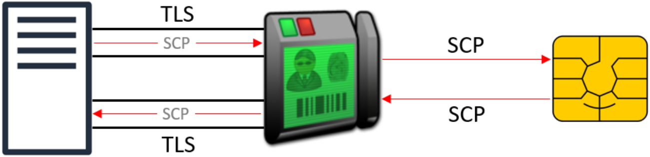

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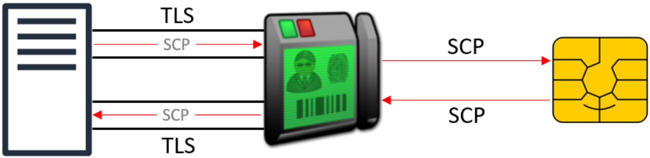

- Establish a secure session between a card and an Off-Card Entity
- 2-steps protocol: Key Exchange + Communication

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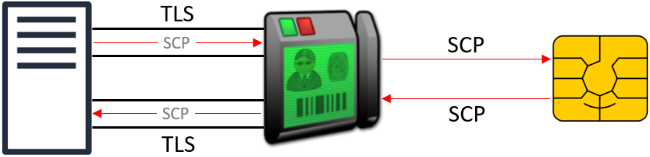
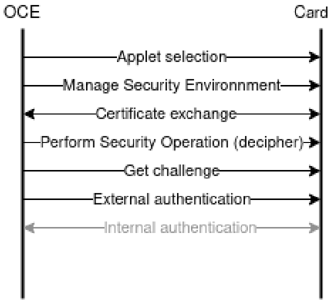


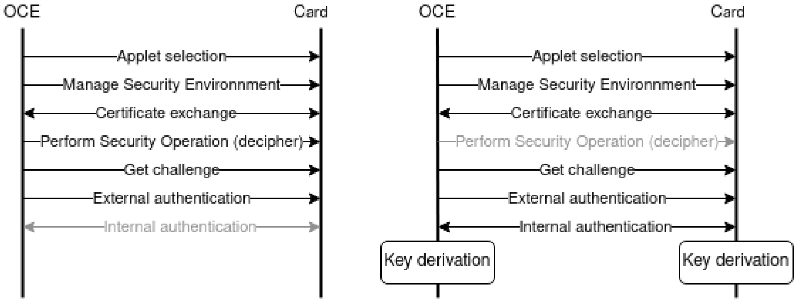
- Establish a secure session between a card and an Off-Card Entity
- 2-steps protocol: Key Exchange + Communication
- SCP10 relies on a Public Key Infrastructure:
  - Both the card and off-card entity have a key pair
  - They use each other public key to encrypt/verify messages

Key Exchange Modes



(a) Key Transport mode

Key Exchange Modes



(a) Key Transport mode (b) Key Agreement mode

Our contributions

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 in the specification to forge a valid certificate, signed by the card (allowing impersonation)
4. Implement a (semi-)compliant version of SCP10 as an applet
5. Propose a secure implementation, with an estimation of the corresponding overhead

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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 attacker 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

She cannot:

- × Have physical access to the card
- × Break the cryptographic primitives

Notation & Reminders

Acronyms

- APDU: Application Protocol Data Unit
  Message format of request send to the card
- TLV: Tag Length Value
  Data structure used to ease parsing
- CRT: Control Reference Template
  Data structure defining a symmetric key and its usage
- IV: Initialization Vector
  Initialisation vector used to initialize symmetric encryption

RSA and padding

RSA:

$pub = (n,\ e)$
$priv = (n,\ d)$

$$\textit{Encryption:}\quad c = m^e \mod n,$$
$$\textit{Decryption:}\quad m = c^d \mod n.$$

$$\textit{Signature:}\quad s = RSA_{sign}(m, priv),$$
$$\textit{Verification:}\quad m == RSA_{ver}(m, pub)\ ?$$

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PKCS#1v1.5 padding:

$$\textit{Enc:}\ \texttt{EME-PKCS1-v1\_5(m)} = \texttt{0x00 || 0x02 ||} \underbrace{\texttt{PS}}_{\text{random bytes}} \texttt{|| 0x00 || m}$$

$$\textit{Sig:}\ \texttt{EMSA-PKCS1-v1\_5(m)} = \texttt{0x00 || 0x01 || 0xFF..FF || 0x00 || m}$$

Deterministic RSA Padding

Perform Security Operation

Perform Security Operation APDU:

```
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```

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$$\texttt{M: params || CRT [|| CRT]} \xrightarrow{\text{padding}} \texttt{EM}$$

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$\rightarrow$ Hybrid between EME and EMSA

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$$\texttt{CRT: } \underbrace{\texttt{header}}_{\texttt{[6,8] fixed bytes}} \texttt{ || } \underbrace{\texttt{key}}_{\texttt{[16,24] bytes}} \texttt{ [|| 91 08 } \underbrace{\texttt{iv}}_{\texttt{8 bytes}} \texttt{]}$$

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⇒ Only few unknown bytes (compared to the modulus size)

Coppersmith's Low Exponent Attack

Coppersmith attack:[1]

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

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

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

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In practice...

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⚠ Bigger RSA modulus is not enough (makes the attack easier)

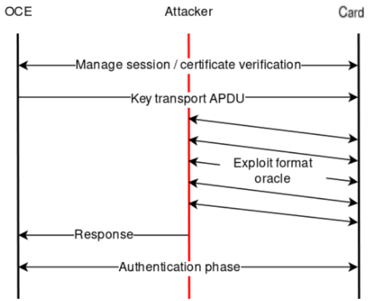
⚠ "Classic" PKCS#1v1.5 padding may not be a valid solution...

Padding Oracle on Key Transport

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



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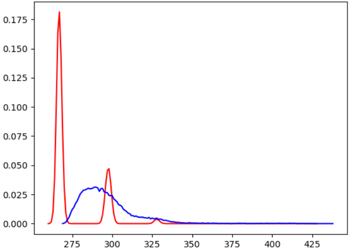

- Large number of query needed
  - On average 28000 queries $\rightarrow \approx$ 2h30
  - Significant communication overhead
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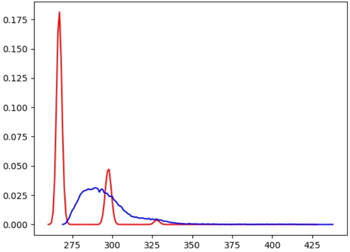

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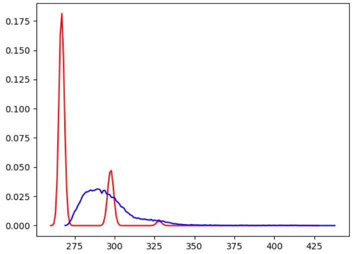

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Key Reuse

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Design flaw:

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- Valid signature forgery using Bleichenbacher's attack
  - On average 74838 queries $\rightarrow \approx$ 7h
- Certificate forgery, signed by the card $\Rightarrow$ card impersonation in all future sessions
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$\Rightarrow$ Key isolation, at least between confidentiality and authentication

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
- Switching from null to random IV for CBC encryption
  - Negligible overhead

Global Overhead[1]

		Original	Secure	Diff.
Key Transport, (mutual authentication)	Cert. verification (card)	0.92	2.06	+124%
	Cert. verification (OCE)	0.15	0.24	+60%
	PSO (decipher)	0.15	0.16	+6%
	External authentication	0.68	0.8	+18%
	Internal authentication	0.73	0.71	-3%
	Total	**2.76**	**4.11**	**+49%**
Key Transport, (external authentication only)	Cert. verification (card)	1.13	2.44	+116%
	Cert. verification (OCE)	0.15	0.24	+60%
	PSO (decipher)	0.15	0.16	+6%
	External authentication	0.72	0.82	+14%
	Total	**2.31**	**3.81**	**+65%**
Key Agreement	Cert. verification (card)	1.18	2.12	+80%
	Cert. verification (OCE)	0.15	0.24	+60%
	PSO (decipher)	0.15	0.16	+6%
	External authentication	1.61	1.43	-11%
	Internal authentication	0.85	0.80	-6%
	Total	**4.09**	**4.90**	**+20%**

[1] Measure done on a NXP J3H145 JCOP3 JavaCard 3.0.4

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	External authentication	0.68	0.8	+18%
	Internal authentication	0.73	0.71	-3%
	Total	**1.56**	**1.67**	**+7%**
Key Transport, (external authentication only)	PSO (decipher)	0.15	0.16	+6%
	External authentication	0.72	0.82	+14%
	Total	**0.87**	**0.98**	**+13%**
Key Agreement	PSO (decipher)	0.15	0.16	+6%
	External authentication	1.61	1.43	-11%
	Internal authentication	0.85	0.80	-6%
	Total	**2.61**	**2.39**	**-10%**

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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 is taking our recommendations into account

Thank you for your attention !