Implementing Selective Disclosure Protocols on Java Cards. A first experience report.

Hendrik Tews Bart Jacobs

Radboud Universiteit Nijmegen
The Netherlands

WISTP, September 3, 2009

- Hendrik left Nijmegen in June 2009 (and is on *Elterngeld* now).
- Wojciech Mostowski and Pim Vullers will continue the work.
- Sponsored by the NLnet foundation through the OV-chipkaart project.

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Outline

Introduction

Performance critical part: Multi-powers on Java Card

OV-Chip 2.0 Applet: Structure and Performance

Conclusion

Identity-based Authentication

For example with the Mifare Classic chip card

- used in
  - the Dutch OV-chipkaart
  - London's Oyster card
  - Hong Kong's Octopus card
  - access control at Radboud Universiteit
  - ...
- fixed anti-collision UID to facilitate tracing people on the street
- fixed application level identity to facilitate tracing customers

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The OV-chip 2.0 project

Design and (partially) implement a privacy friendly alternative for the Dutch OV-chipkaart

- single, nationwide chip card for all public transport in the Netherlands
- built-in privacy: nobody can generate traces of customers or even identify customers
- implementation on Java Card with a free license

Until early 2009

- focus on **selective disclosure** and **blinded issuing** by Stefan Brands

Now and near future

- develop new protocols based on elliptic curve pairing

Privacy friendly authentication

Protocol for Selective Disclosure

- customer possesses attributes
  (password, private key, age, permission to board a train, . . .)
- proves knowledge/possession of his attributes
- **without** disclosing some (all) attributes

Protocol for Blinded Issuing

Generate signatures such that the signing authority

- **does not** know what is signed
  (not requiring the disclosure of attributes when obtaining a signature)
- **does not** learn the resulting signature
  (permitting the customer to stay anonymous after getting a new signature)

Stefan Brands. *Rethinking Public Key Infrastructures and Digital Certificates: Building in Privacy*. MIT Press, 2000. See www.credentica.com.

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Protocol Example

(here for proving knowledge of two attributes only)

System setup (glossing over side conditions)

$\mathbf{n} = \mathbf{pq}$ RSA modulus (about 1280 bits)

$\mathbf{g_1, g_2} < \mathbf{n}$ public bases

$\mathbf{v}$ public RSA exponent (about 160 bits)

Card setup

$\mathbf{a_1, a_2} < \mathbf{v}$ attributes of the card

$\mathbf{b} < \mathbf{n}$ blinding

$\mathbf{A} = (\mathbf{b^v\, g_1^{a_1}\, g_2^{a_2}}) \mod \mathbf{n}$ blinded attribute expression

Protocol Example (cont.)

Card proves knowledge of a_1 and a_2 to a **G**ate

Card Commitment

$$\mathrm{C} \longrightarrow \mathrm{G} \;:\; A, w \quad \text{where } w = \left(\beta^v \, g_1^{\alpha_1} \, g_2^{\alpha_2}\right) \bmod n \text{ for random } \beta, \alpha_i$$

Gate Challenge

$$\mathrm{C} \longleftarrow \mathrm{G} \;:\; \gamma < v \quad \text{random}$$

Card Response

$$\mathrm{C} \longrightarrow \mathrm{G} \;:\; r_1, r_2, s \quad \text{where} \begin{cases} r_i = (\gamma a_i + \alpha_i) \bmod v \\ q_i = (\gamma a_i + \alpha_i) \div v \\ s = \left(\beta \, b^\gamma \, g_1^{q_1} \, g_2^{q_2}\right) \bmod n \end{cases}$$

Acceptance Check

Gate accepts the prove if $\quad s^v \, g_1^{r_1} \, g_2^{r_2} = A^\gamma \, w \pmod{n}$

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Performance critical part: Multi-Powers on the card

Modular Multi-Powers

- $(g_1^{a_1}\, g_2^{a_2}\, \cdots\, g_n^{a_n}) \mod n$
- bases of 1300–2000 bits, exponents of 160–200 bits

Performance measurements for

- 4 attributes + blinding
- short term security: 1300 bit bases/modulus, 160 bit exponents
- SUN Java JRE 1.6
- Intel Core Duo 1.66 GHz

SUN BigInteger	0.0395 seconds	single modular powers
our Bignat	0.0264 seconds	simultaneous squaring
Java Card		estimation for pure Java Card
Crypto Coprocessor		potentially

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Crypto Coprocessor	0.1 seconds	potentially

Java Card potential

Cryptographic Coprocessor

- does modular multiplications for big integers in hardware
- used for high-level cryptographic operations in Java Card (RSA, DSA, . . .)
- accessible via `javacardx.framework.math.BigNumber` in Java Card 2.2.2
- estimated 0.3 *milliseconds* for a modular big integer multiplication

However . . .

Java Card Limitations

BigNumber class in Java Card 2.2.2

- only addition, subtraction, multiplication
- no division, no modular multiplication, no modular exponentation
- found only 2 cards on this planet that implement Java Card 2.2.2: Athena IDProtect and a new NXP card
- `BigNumber` is optional and not implemented on these cards

Java Card 2.2.1

- no `BigNumber` in Java Card 2.2.1
- trick a high-level crypto operation of the Java Card API into an arithmetic operation on big integers
- for security these crypto operation contain random padding, which cannot be controlled from the interface
- **only exception:** `ALG_RSA_NOPAD` **cipher computes cipher text** $g^a \mod n$ **for plain text** g **and key** n, a

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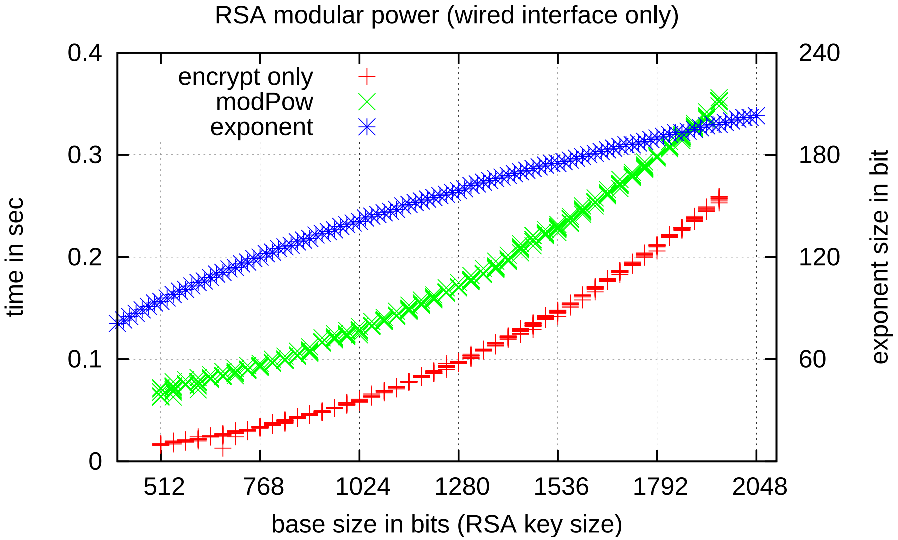
Modular exponentiation on the crypto coprocessor



(for many more charts go to ovchip.cs.ru.nl/OV-chip_2.0_progress)

Modular Products?

$(a\,b) \mod n$

- no access to the cryptographic coprocessor for multiplication on currently available Java Cards
- Montgomery multiplication in Java takes 25 seconds for 1280 bit numbers

$(a+b)^2 = a^2 + 2ab + b^2$

- i.e., $ab = \frac{(a+b)^2 - a^2 - b^2}{2}$
- can be turned into a modular multiplication for odd moduli
- requires 2 subtractions, 1–4 additions, 1 right shift
- called *squaring multiplication*

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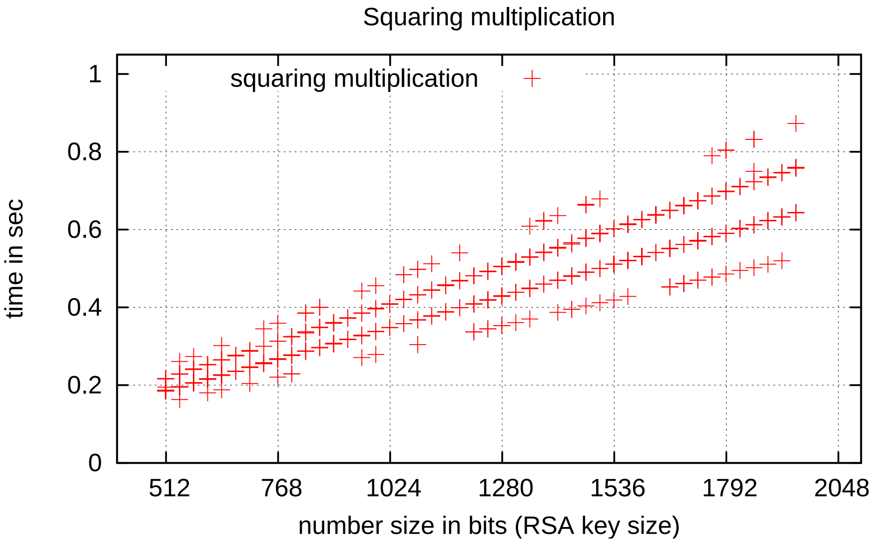
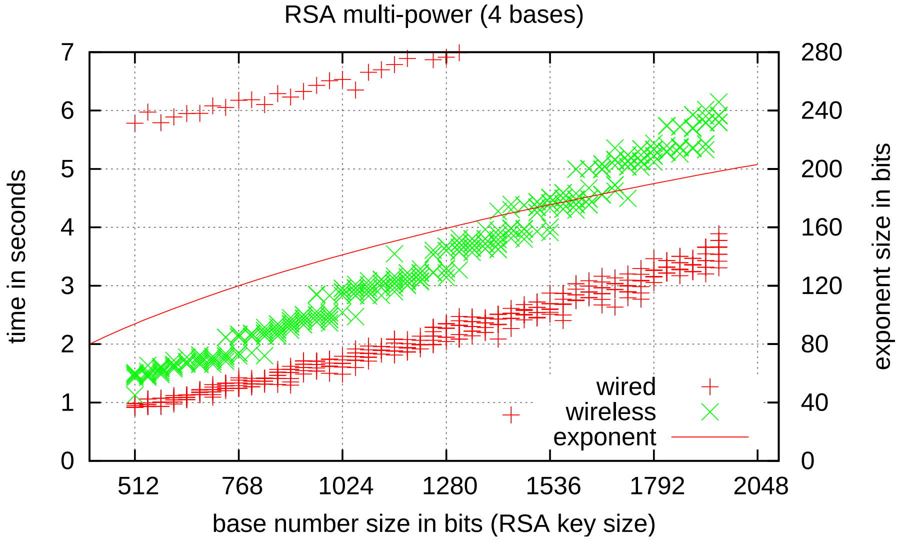
Performance of Squaring Multiplication



Multi-Powers using the cryptographic coprocessor



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Implementation

Features implemented

- key setup, choose number of attributes, selection of bases (g_i)
- applet initialisation
  - attribute selection (a_i)
  - download key material, bases, attributes to the card
  - first blinding, signature generation
- proof protocol
  - signature check
  - card proves knowledge of all its attributes
- resign protocol
  - arbitrary attribute update
  - new blinding, new signature

Implementation (cont.)

Features missing

- selective disclosure of some attributes
- proving relations (balance $>$ €20)
- ...

2 Applets

Coprocessor-enabled applet: Uses the crypto coprocessor as far as possible

Pure Java Applet: Only JVM, without crypto coprocessor, very very slow

One Host driver: can talk to both applets

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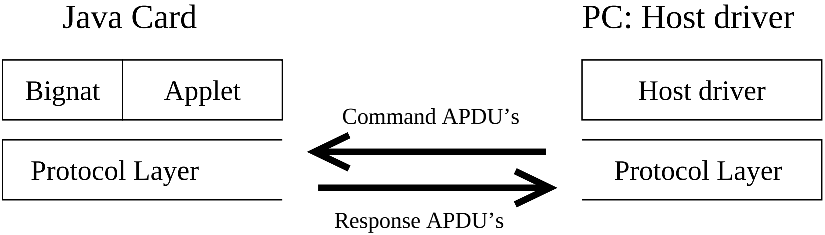
Application structure

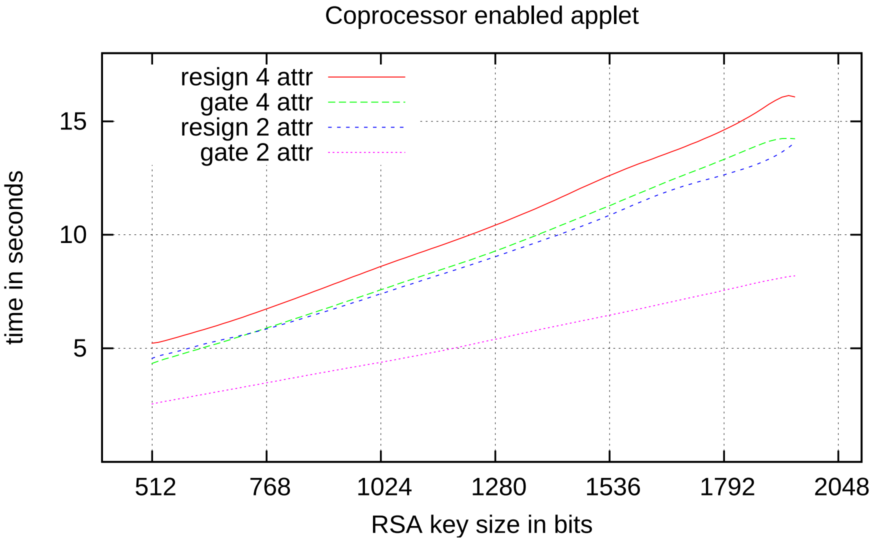


Bignat newly written big-integer library for Java Card
with convenience methods for the crypto coprocessor
uses byte/short normally, but can be compiled using int/long

Protocol Layer Custom remote method library
supporting arbitrary many arguments and results up to 32 KByte,
also supporting easy applet debugging on the PC

Host driver relies on `java.math.BigInteger`

Coprocessor-enabled applet



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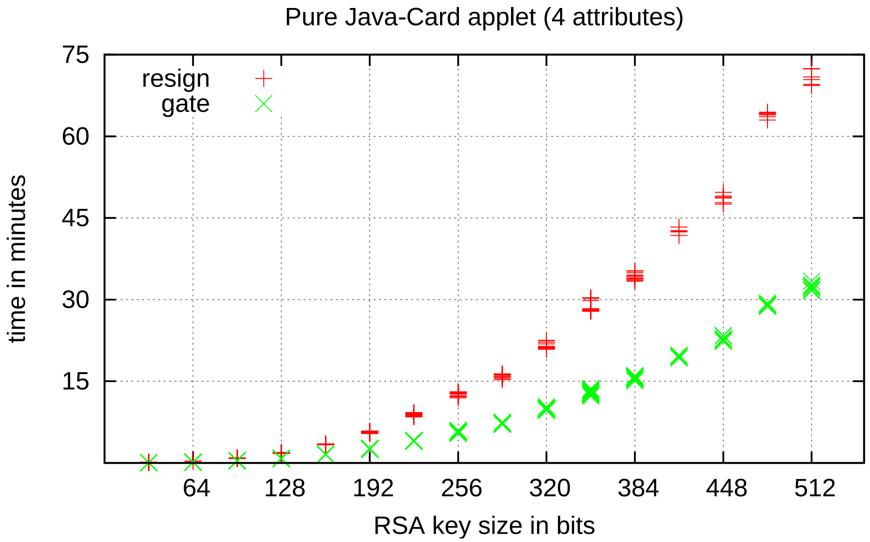

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Java Card API does not facilitate new cryptographic protocols

- necessary big-integer operations not supported in the API
- no card seems to implement `javacardx.framework.math.BigNumber`
- most cards *do* implement the needed operations in a native library
- API limitations force big-integer operations on the Java Card VM **with terrible performance results**

Achievements

Brands protocols: implementation on real Java Card

- 5–10 seconds for RSA keys with short term security
- not ready for public transport
- ready for special usage, e.g., over the internet
- <1 second possible with optimal crypto coprocessor access

Bignat library for mutable big-integer operations on Java Card

Protocol Layer Custom remote method library (up to 32KB arguments/results)

Download **(almost) all sources at http://www.sos.cs.ru.nl/ovchip/**

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General Java Card

- Java Card is not compatible with Java
  System.arraycopy versus javacard.framework.Util.arrayCopyNonAtomic or javacard.framework.Util.arrayCopy
- Java is not really suited for programming Java cards
  idealised Java: all platforms are identical/no conditional compilation
  reality: Java and Java Card differ a lot!

Needed

- additional classes in the Java Card API with
  - modular exponentiation, multiplication, addition/subtraction
  - division, modulus
  - modular inverse
  - elliptic curve point addition, scalar point multiplication
- Cards implementing `javacardx.framework.math.BigNumber`
- Cards supporting `int`
- conditional compilation for code running on both JVM and JCVM

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