Selective disclosure protocols on Java Card Eine Fallstudie für das niederländische Nahverkehrssystem

Hendrik Tews

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Outline


Alléén
ov chipkaart
GVB


OV-Chipkaart


Ontwikkeling Reisgebied OV-chipkaart
Reisgebied per 11 februari 2010
Trein NS
Trein overige
OV-chipkaart enige vervoerbewijs
Volgt in 2e kwartaal 2010
Volgt later
www.ov-chipkaart.nl

Technologie und Probleme

- $\approx$ 15 Verkehrsunternehmen beteiligt
- $>$ 600 Millionen € Kosten bisher
- Identitätsbasiert
- basiert auf Mifare-Classic und Mifare-Ultralight
  - genauso wie Oyster (London), Octopus (Hong Kong), Emeal vom Studentenwerk Dresden, Zugangskarten für diverse Universitäten/Ministerien/Militärbasen
  - konstante Anti-Kollisions ID's
  - proprietäre Verschlüsselung 2008 gebrochen
  - Karten können geklont werden
  - Saldo kann erhöht werden
  - System ist trotzdem sicher!
- anonyme Karten nur gegen Aufpreis (und ohne Ermäßigungen)
- zentrale Datenbank mit allen Transaktionen

OV chip 2.0

- Design und Implementierung einer Nahverkehrskarte mit Vertraulichkeit und Integrität
- durch die nInet-Stiftung gesponsort
- Implementierung auf Java Card

Outline

Kenntnis eines Geheimnisses beweisen, ohne es zu verraten

- dem Geldautomaten beweisen, dass man die PIN kennt, *ohne sie einzutippen*
- im Whiskyladen beweisen, dass man über 18 ist, *ohne Geburtsdatum oder Alter zu verraten*
- beweisen, dass man eine gültige Fahrkarte hat, *ohne deren Seriennummer zu verraten um anonym zu reisen*

Schnorrs Identifikations protokoll

Parameter Primzahl p (1024 bit), Primzahl q (160 Bit) sodass $q \mid p-1$
α Generator modulo p, $g = \alpha^{(p-1)/q} \pmod p$ hat Ordnung q

Schlüssel Beweiser Brita wählt privaten Schlüssel $x < q$
Britas öffentlicher Schlüssel $y = g^x \pmod p$

Protokoll

Beweiser Brita		Prüfer Peter
$r < q$, zufällig, $t = g^r$	$\xrightarrow{t}$	
	$\xleftarrow{c}$	challenge $c < q$, zufällig
berechnet $s = r + cx$	$\xrightarrow{s}$	Beweis akzeptiert, falls $g^s \stackrel{?}{=} t\,y^c$

Test $g^s = g^r \cdot (g^x)^c = t \cdot y^c$

Outline

Java Card Überblick

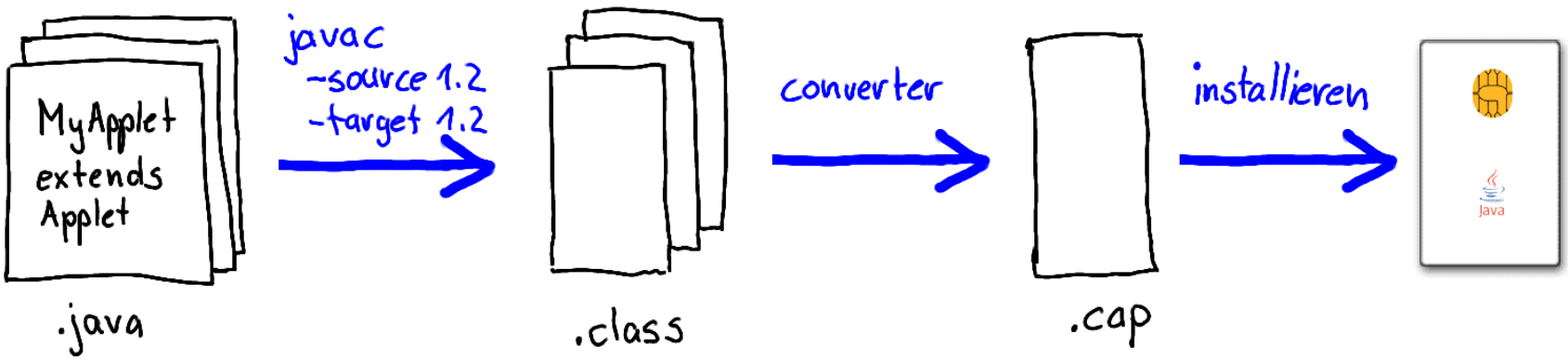
- 30 MHz CPU
- 160 KB ROM (64 K frei), 72 KB EEPROM, 4 K RAM ($\approx$ 2 K frei)
- Java byte code sadd dauert 15–45 μs
- speziell gesicherte virtuelle Machine für Java Card
- Transaktionen, atomare Speicherzugriffe
- spezielle Hardwarebeschleunigung für SHA1, DSA, DES, RSA, Elliptic-curve Diffie-Hellmann
- Java Card $\subset$ Java, trotzdem nicht kompatibel

unterstüzt	nicht unterstüzt
boolean, byte, short	long, double, float
32-bit-int optional	enums, assertions
eindimensionale arrays	mehrdimensionale arrays
packages, classes	reflection
interfaces, exceptions	threads, serialization, cloning
GC optional, nicht automatisch	

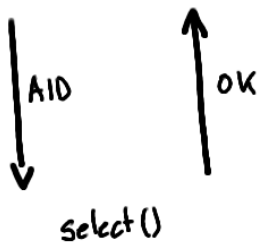
Java Card Überblick II

- Versionen
  - **2.2.1** von 2003
    - 10–20 €
    - max 256 Byte Daten per APDU
  - **2.2.2** von 2006
    - 32KByte APDU's
    - optional javacardx.framework.math.BigNumber gibt Zugriff auf Crypto-Coprozessor
    - Karten praktisch nicht erhältlich; bekannte Exemplare implementieren BigNumber nicht
  - **3.0** Spec im April 2008 veröffentlicht
    - erste Produktionsmuster
    - Web-server auf der Karte
- Java Card RMI
  - Remote Method Invocation for Java cards
  - serialisierte Argumente/Resultate müssen in eine APDU passen
  - praktisch kaum benutzbar

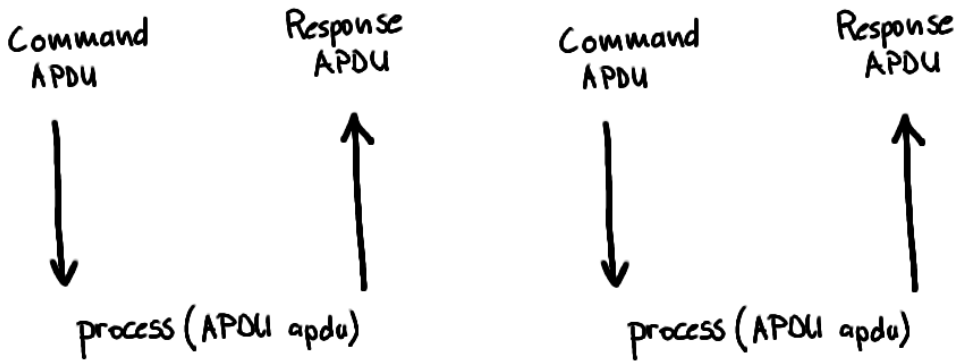
Applet Lebenslauf



Applet wählen



Kommunikation



Probleme für nicht-triviale Applets

1. Debugging, gemeinsamer Code für Applet und Host
2. potenzieren von Zahlen mit 1000 – 2000 Bit
3. Argumente/Resultate passen nicht in eine APDU
   - bis zu 3800 Byte (15 APDU's)
   - Größe variiert je nach Konfiguration
     - 4 Attribute, 1952 Bit RSA: 753 Byte (3 APDU's)
     - 2 Attribute, 512 Bit RSA: 213 Byte (1 APDU)

Gemeinsamer Code für Applet und Host

- z.B. für Konfiguration, serialisierbare Datentypen, RMI Signaturen
- Debugging: Applet- *und* Hostcode laufen zusammen auf *einer* JVM
- Inkompatibilitäten zwischen Java Card und Java
  - `package ds_ov2_srsa` vs. `package ds.ov2.bignat`
  - `import java.security.MessageDigest` vs. `javacard.security.MessageDigest`
  - `arrayCopyNonAtomic` oder `arrayCopy` vs. `arraycopy`
- keine bedingte Kompilation in Java
  (es gibt ja Reflexion — außer in Java Card)
- copy & paste ist Standardlösung

- Meine Lösung
  - cpp
  - `sed -e 's|^# |//# |'`
  - emacs defadvice für next-error

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Bignat Programmbibliothek

- keine Big-Integer Bibliothek für Java Card verfügbar
- Portierung auf Java Card ist sehr aufwendig und wenig sinnvoll (immutable, GC)

Bignat

- ziemlich anwendungsspezifisch (positive Zahlen fester Größe)
- mutable, allokationsfrei
- spezielle Methoden zum Rechnen auf dem Crypto Coprocessor
- Basisdatentypen sind byte/short *oder* int/long

Protocoll Layer: RPC für Java Card bis 32KB

- Programmbibliothek für
  - (De-)Serialisierung von Argumenten und Resultaten
  - Aufteilung in mehrere APDU's
- idl Compiler (perl, 1500 LoC) erzeugt aus

```
protocol resign
    step sig_hash: d.host_alpha, d.remainders -> d.sig_remainder
        call card.make_sig_hash()
```

  - RPC Beschreibung als Java Objekt
  - Stub-Code inklusive Typkonvertierungen

```
public BigInteger sig_hash_call(CardChannel _cc, BigInteger _a_1,
                                Host_vector _a_2)
```

  - Resultattypdeklarationen für Methoden mit mehreren Resultaten
  - Testframe Stub-Code führt Methoden direkt aus

Outline

Overview

Protocol for Selective Disclosure

- customer possesses attributes
  (private key, kind of ticket, expiry date, balance, . . .)
- 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)

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Protocol Example

(here for proving knowledge of two attributes only)

System setup (glossing over side conditions)

$n = pq$ RSA modulus (about 1280 bits)

$g_1, g_2 < n$ public bases

v public RSA exponent (about 160 bits)

Card setup

$a_1, a_2 < v$ attributes of the card

$b < n$ blinding

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

Protocol Example (cont.)

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

Card Commitment

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

Gate Challenge

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

Card Response

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

Acceptance Check

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

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Protocol Example (cont. II)

Shortcomings of the partial disclosure protocol

- A is a pseudonym
  need to change β now and then
- card could invent attributes on the fly
  need to sign the blinded attribute expression A

Resign Protocol

- update attributes values (e.g., adjusting the balance)
- card chooses new blinding β
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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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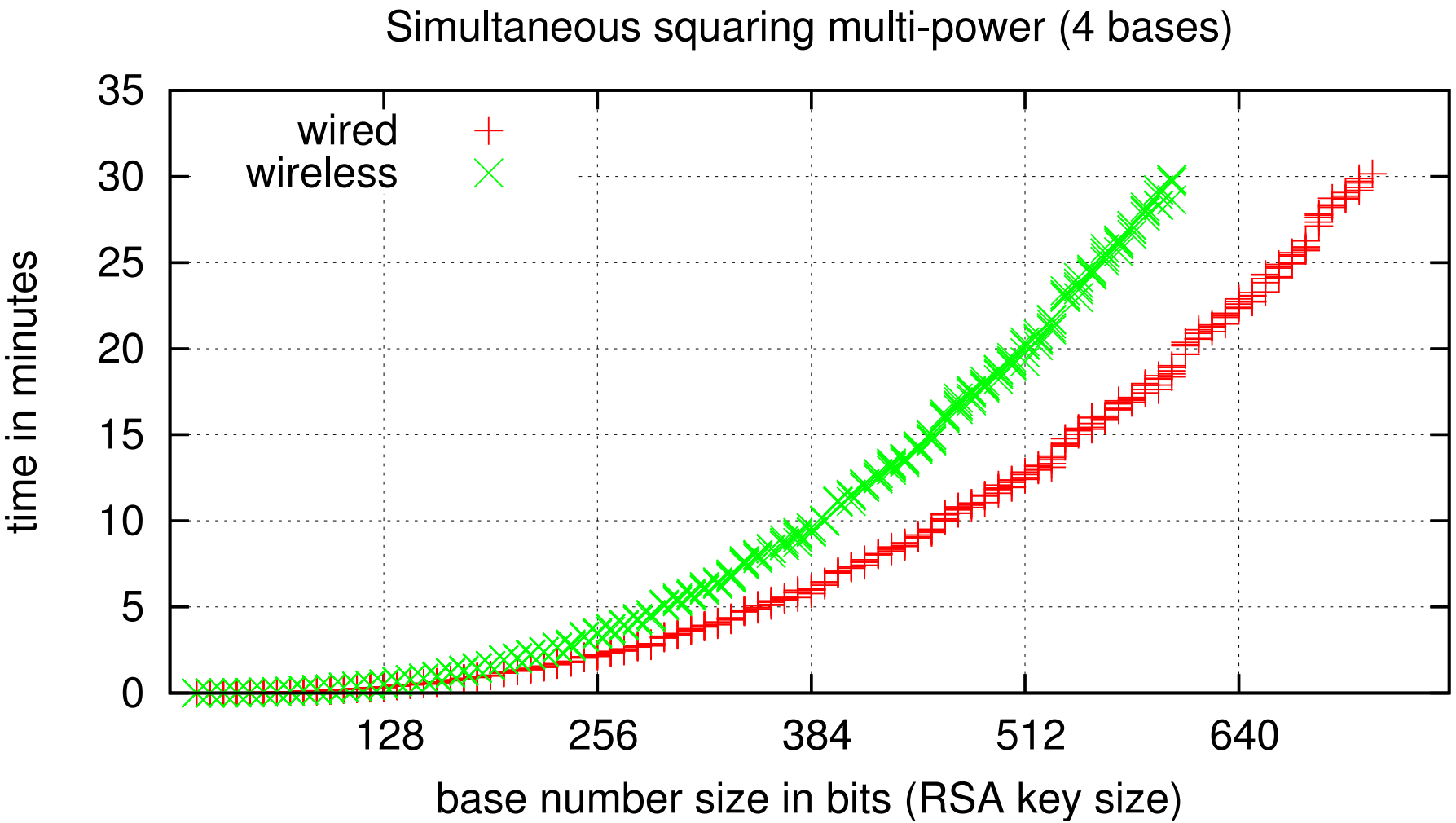
Pure Java Card Multi-Powers



(for much more measurements go to `ovchip.cs.ru.nl/OV-chip_2.0_progress`)

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
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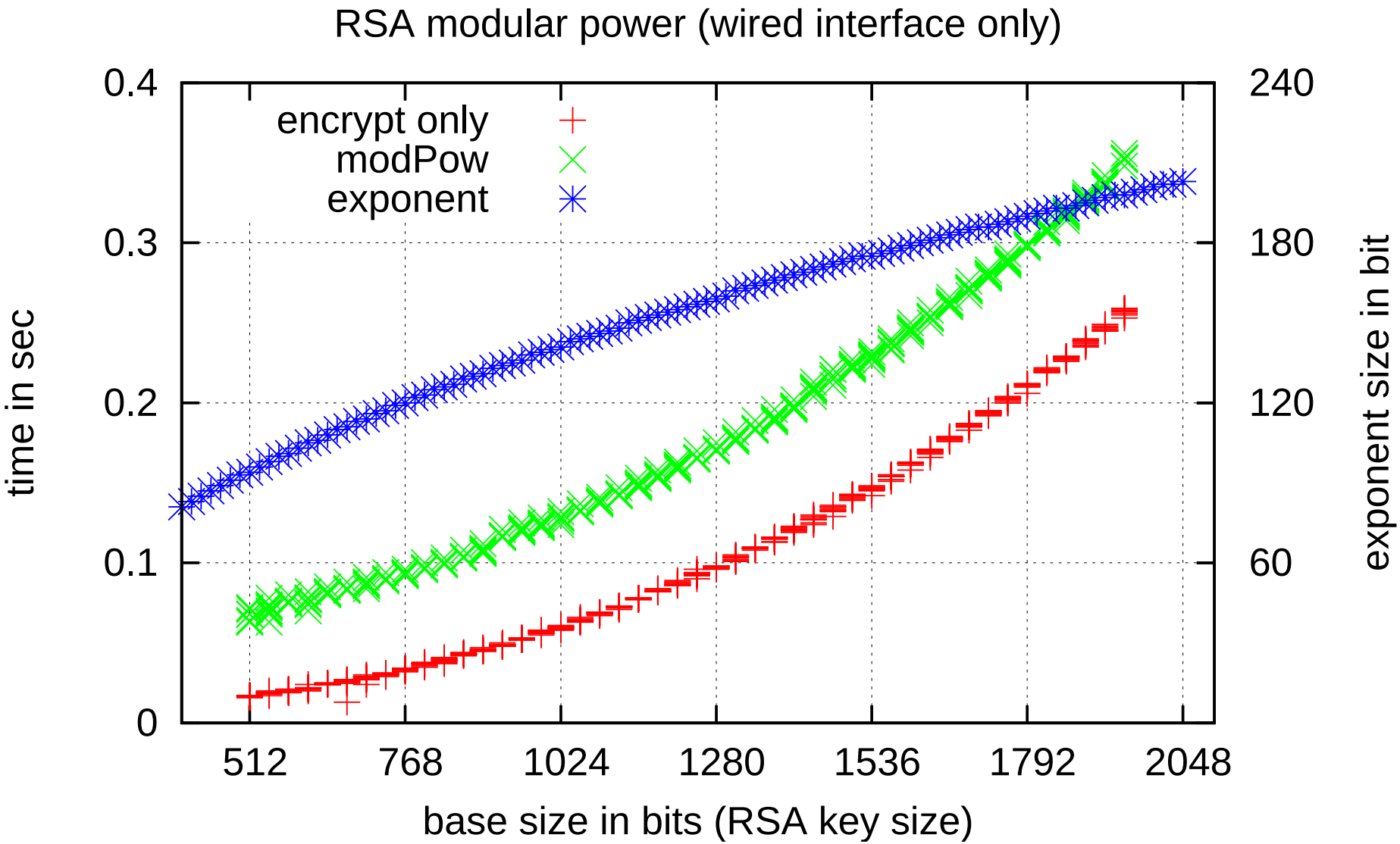
Modular exponentiation on the crypto coprocessor



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

$(a+b)^2 - (a-b)^2 = 4ab$

- can be turned into a modular multiplication for odd moduli
- requires 2 squares, 2 subtractions, 1–3 additions, 1 right shift, 1 comparison
- called *squaring multiplication*

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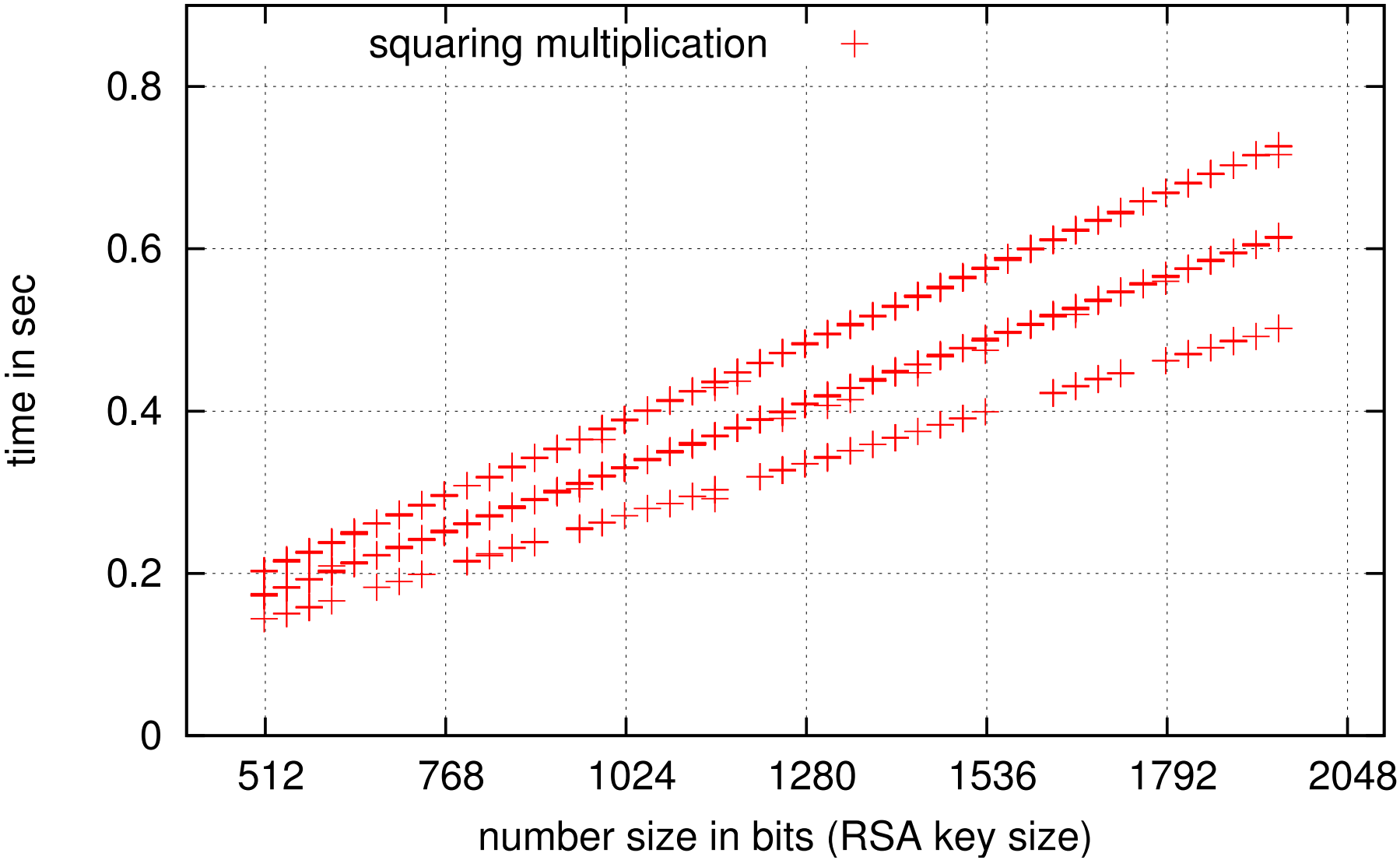
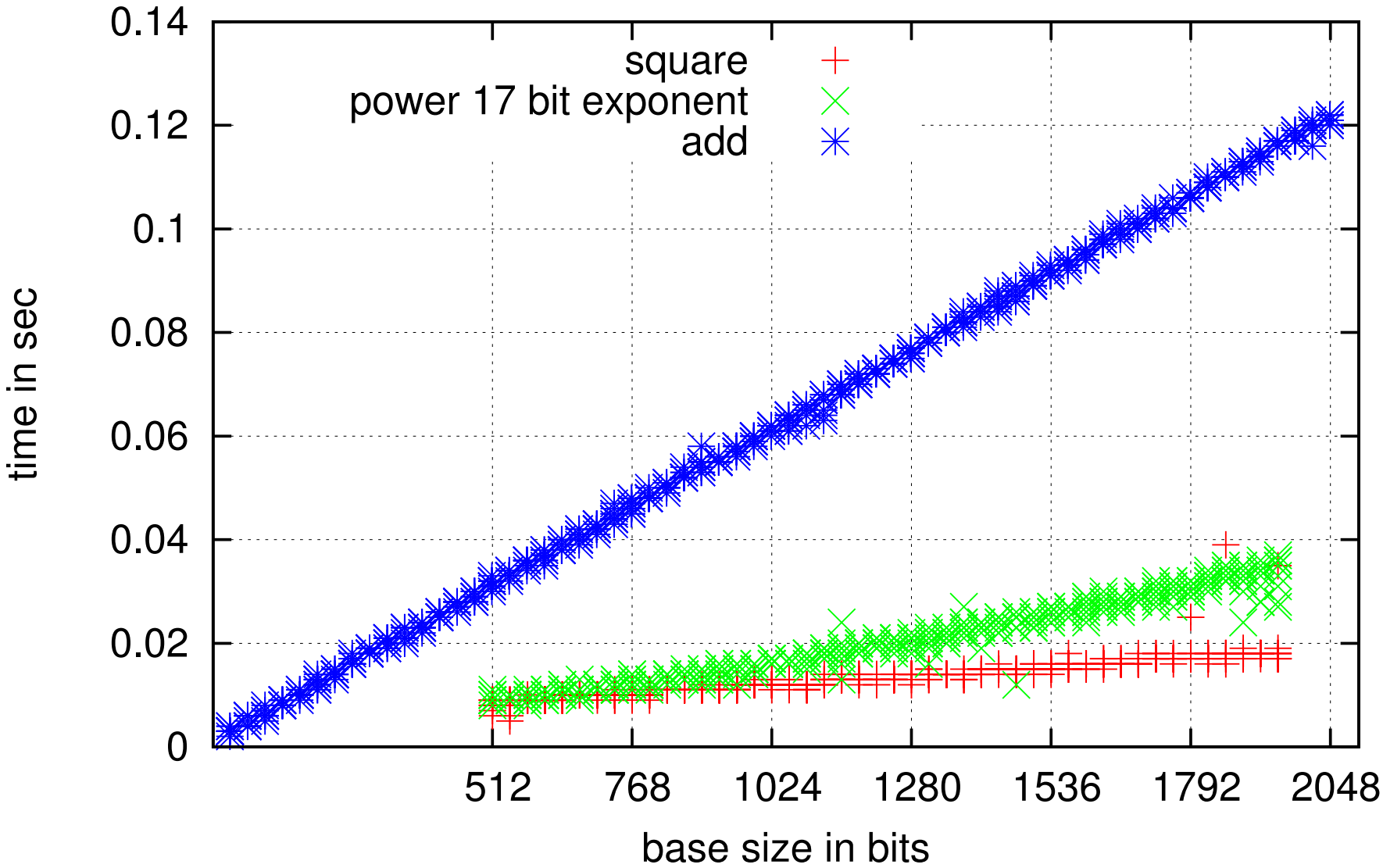
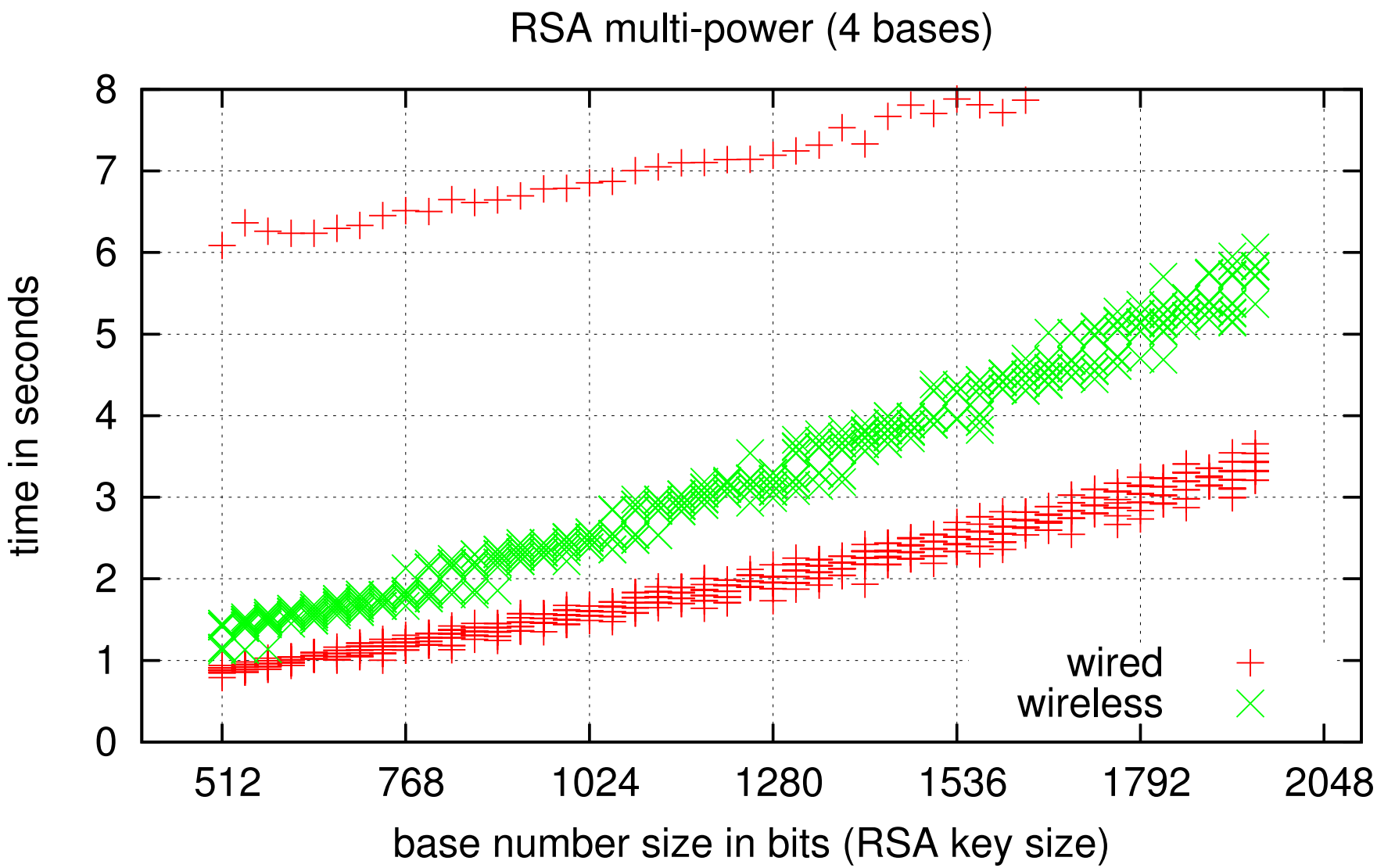
Performance of Squaring Multiplication



Addition and Squaring



Multi-Powers using the cryptographic coprocessor



Outline

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)
- ...

4 Applets

- **Pure** Reines JCVM applet, kein Coprocessor, äußerst langsam
- **Coprocessor + Montgomery Multiplikation**
- **Coprocessor + squaring Multiplikation I** nutzt $2ab = (a+b)^2 - a^2 - b^2$
- **Coprocessor + squaring Multiplikation II** nutzt $4ab = (a+b)^2 - (a-b)^2$
- **Ein Host driver** für alle Applets
- **GUI** für alle Applets

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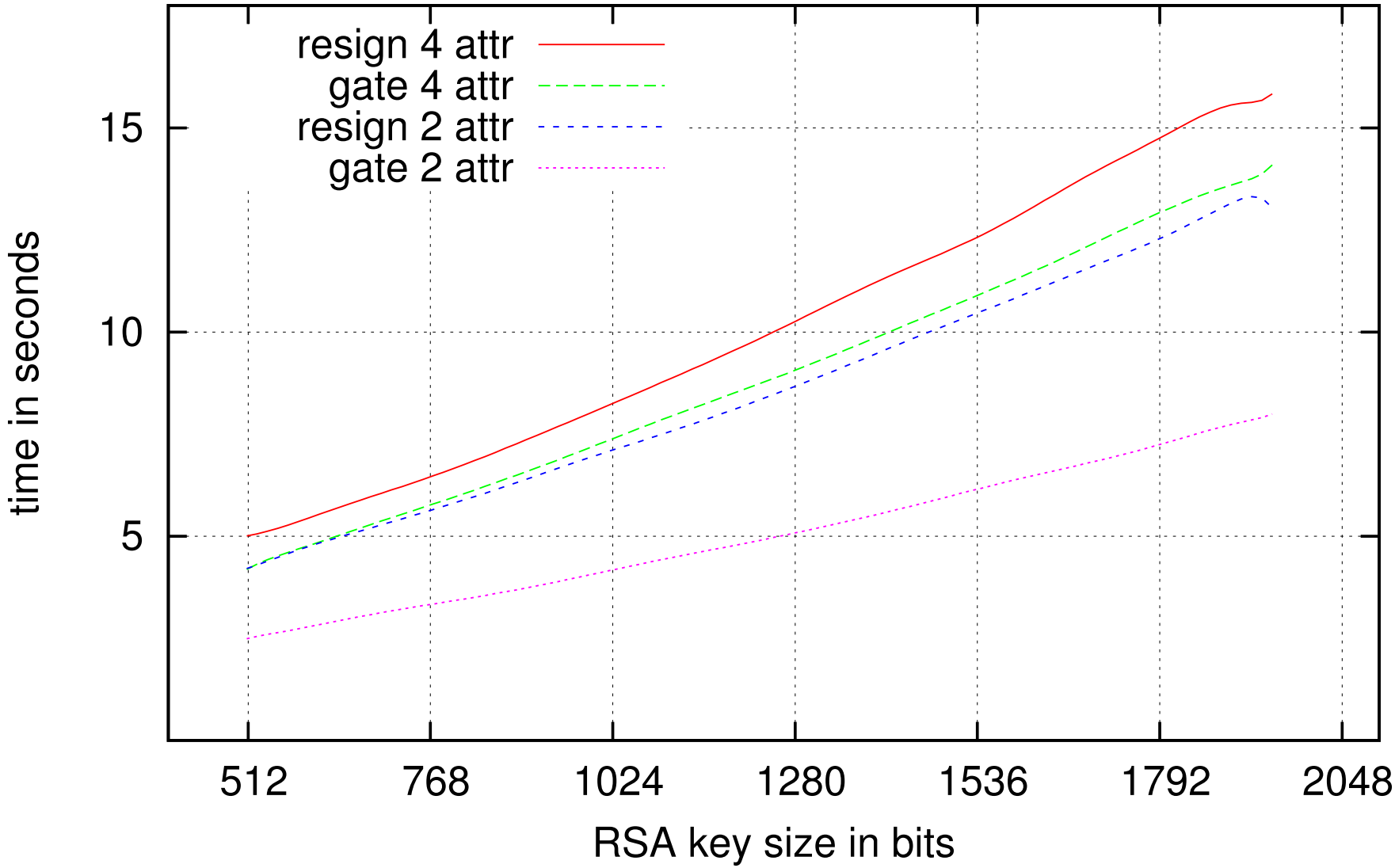
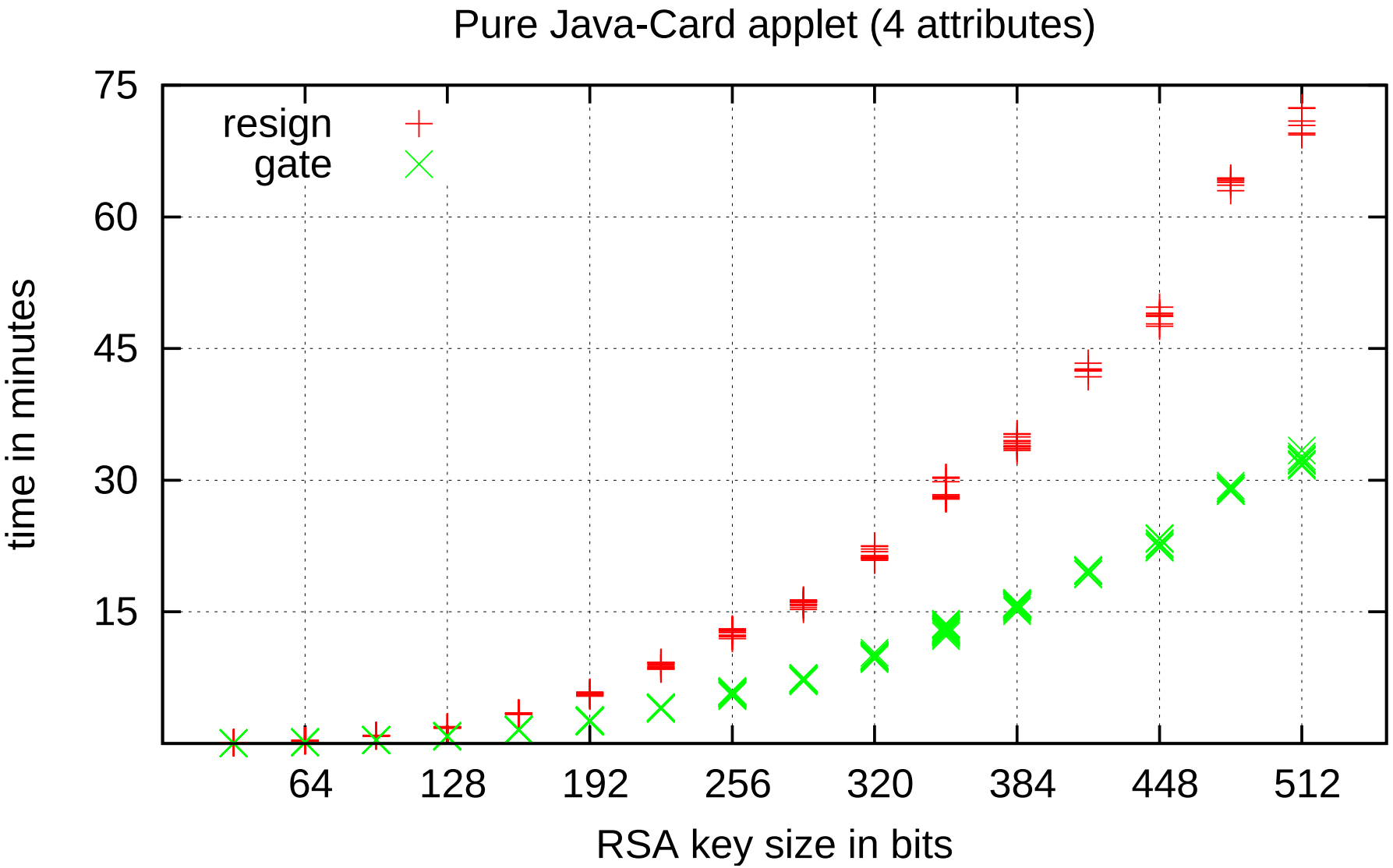
Performance of "Coprocessor + squaring II" applet



Pure Java Card Applet



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Conclusion

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

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  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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- Cards implementing `javacardx.framework.math.BigNumber`
- Cards supporting `int`
- conditional compilation for code running on both JVM and JCVM

Conclusion (cont.)

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

Entwicklung nach Juli 2009

- Elliptische Kurven
- kurze Schlüssel (160–192 Bits)
- Diffie-Hellmann für Elliptische Kurven wird für skalare Multiplikation benutzt
- Laufzeit 2–3 Sekunden für ein Attribut