PV204 Security technologies

Cryptographic smartcards, attacks against two-factor

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CROCS
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Check-in activity: how to stay awake

- Any idea what we can do, prepare, try… to help us stay awake?
- (5 minutes)

Overview

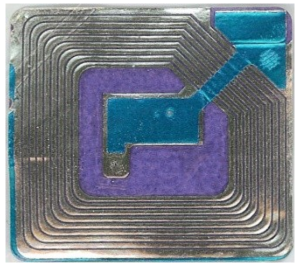
1. What smart cards are?
2. What smart cards are capable of?
3. How to manage smart cards?
4. Lightweight secure channel protocols
5. Two-factor authentication and some attacks

Smart card basics

WHAT A SMART CARD IS?

Basic types of (smart) cards

1. Contactless “barcode”
   - Fixed identification string (RFID, < 5 cents)
2. Simple memory cards (magnetic stripe, RFID)
   - Small write memory (< 1KB) for data, (~10 cents)
3. Memory cards with PIN protection
   - Memory (< 5KB), simple protection logic (<$1)



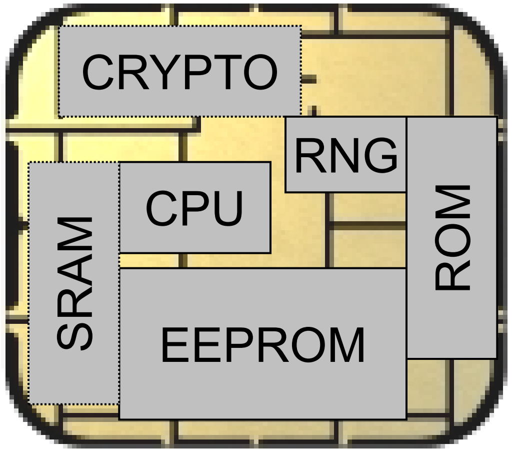
Basic types of (smart) cards (2)

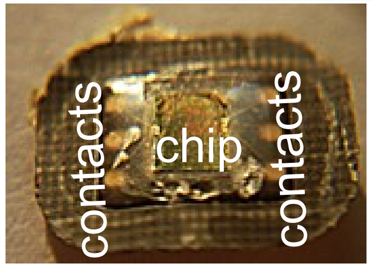
4. Cryptographic smart cards
   - Support for (real) cryptographic algorithms
   - Mifare Classic ($1), Mifare DESFire ($3)
5. User-programmable cryptographic smart cards
   - JavaCard, .NET card, MULTOS cards ($2-$30)

- Chip manufacturers: NXP, Infineon, Gemalto, G&D, Oberthur, STM, Atmel, Samsung...

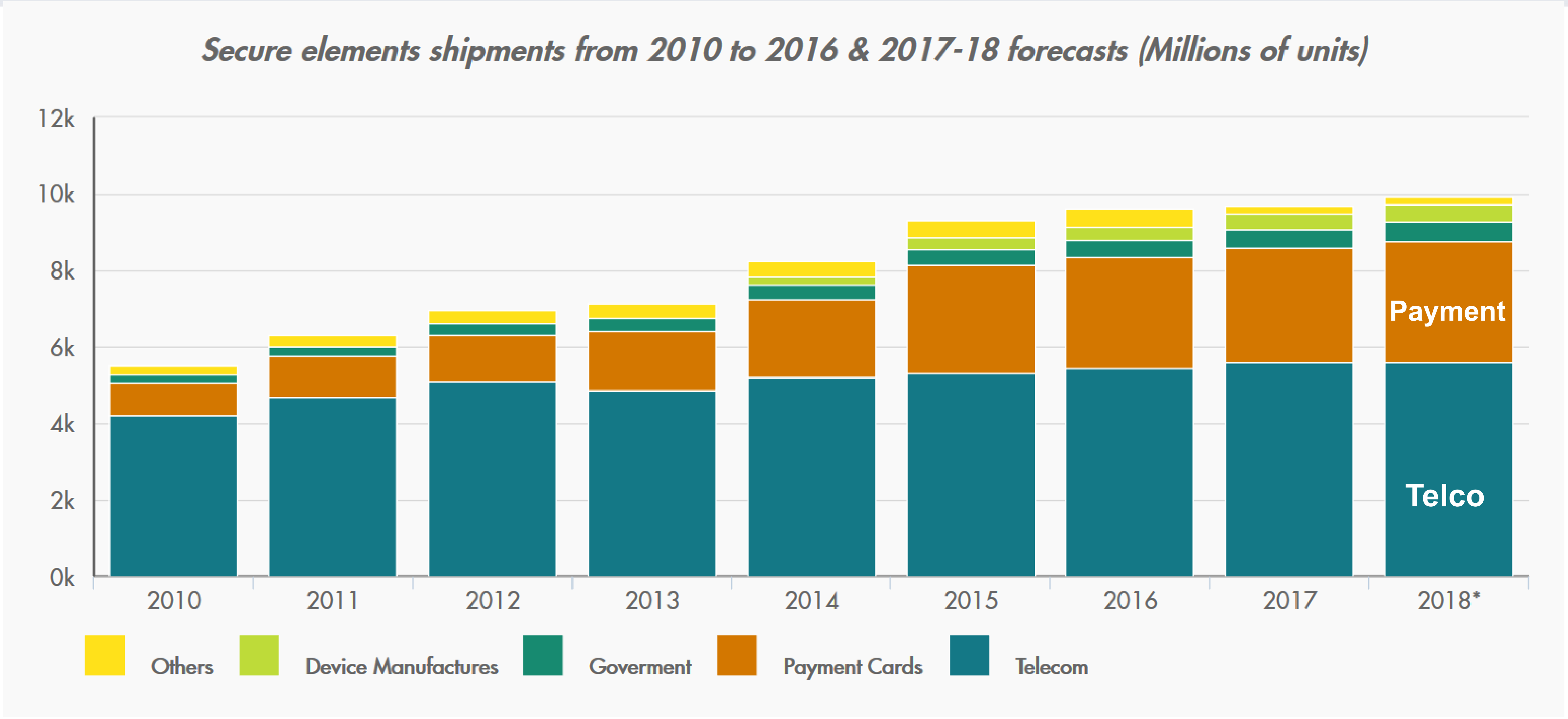
We will mainly focus on these two categories

Cryptographic smart cards





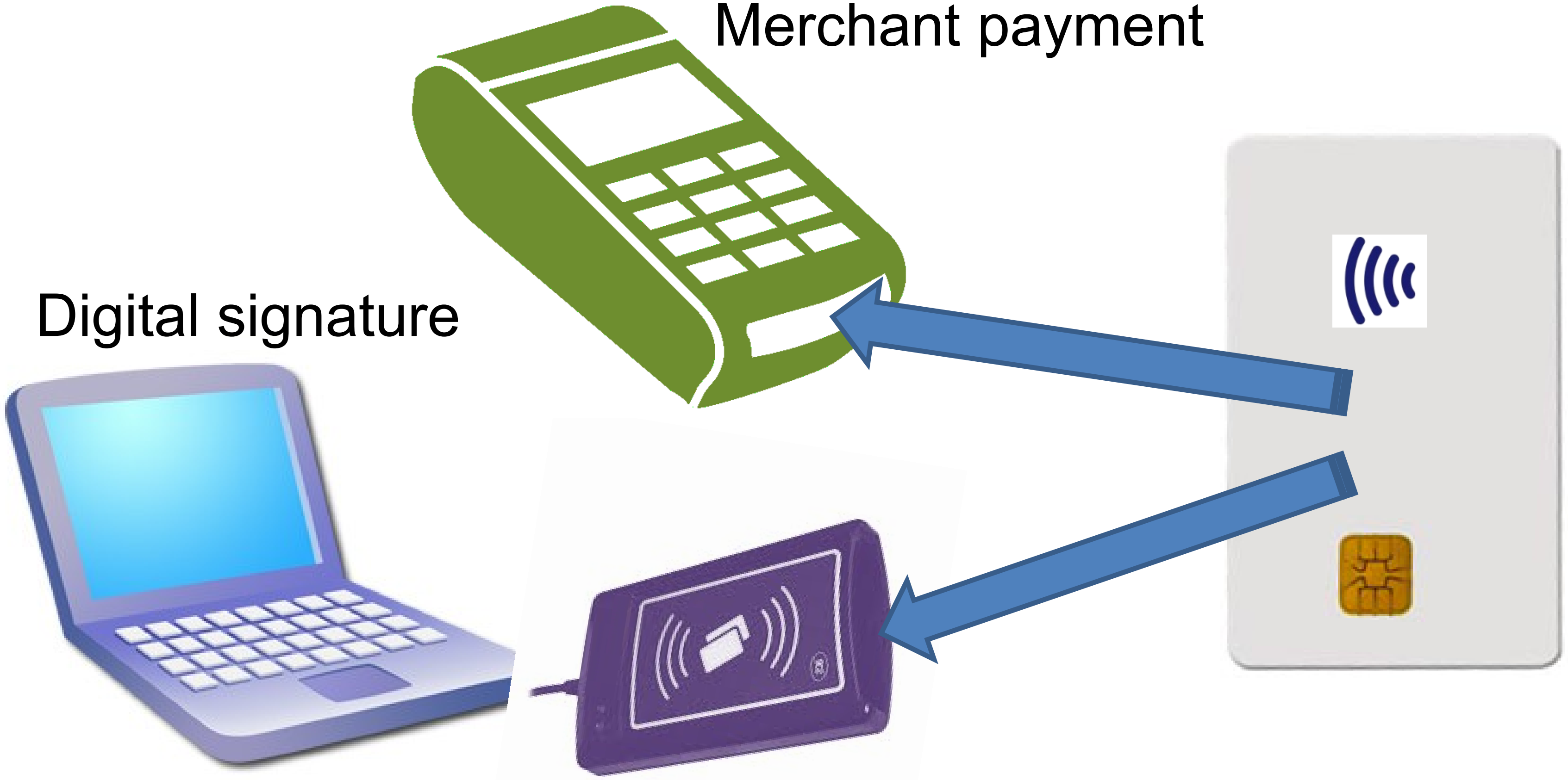
- SC is quite powerful device
  - 8-32 bit processor @ 5-50MHz
  - persistent memory 32-100s kB (EEPROM)
  - volatile fast RAM, usually <<20kB
  - truly random generator, cryptographic coprocessor (3DES, AES, RSA-2048...)
- ~10 billion units shipped in 2018 (EUROSMART)
  - mostly smart cards, telco, payment and loyalty...
  - ~1.5 billion contactless (EUROSMART)
- Intended for physically unprotected environment
  - NIST FIPS140-2 standard, security Level 4
  - Common Criteria EAL4+/5+



http://www.eurosmart.com/facts-figures.html

SMARTCARDS USED IN WIDER SYSTEM

Big picture – terminal/reader and card

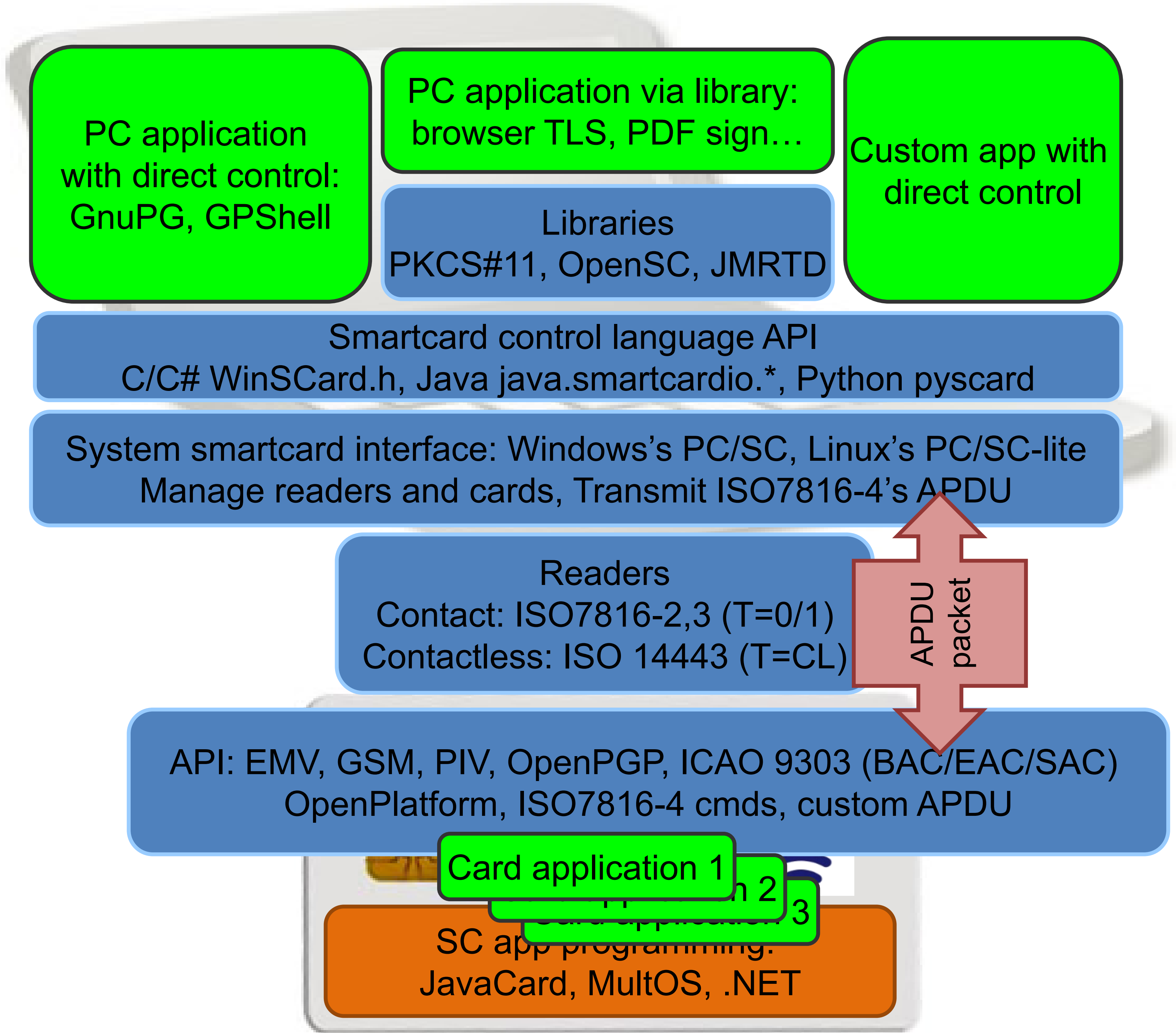


What principles and standards are used?

Group activity: smartcard stack

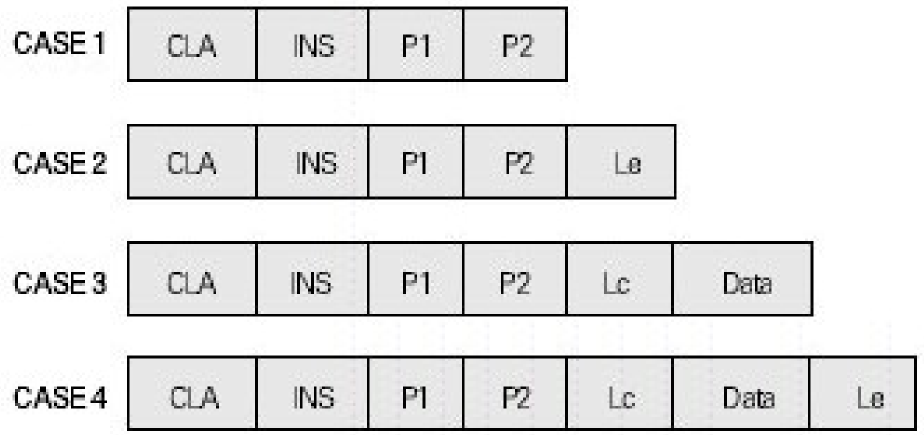
- (Imagine e.g., digital signature application with private key on smartcard)
- Organize and glue floating items into smartcard stack
- Use internet… (but don't google for my slides from previous years ☺)
- Annotate with own comment (what is the item about)
- (15 minutes)

- Stack presented on the next slide, what you placed differently?
- (5 minutes)


PC application with direct control: GnuPG, GPShell
PC application via library: browser TLS, PDF sign…
Custom app with direct control
Libraries PKCS#11, OpenSC, JMRTD
Smartcard control language API C/C# WinSCard.h, Java java.smartcardio.*, Python pyscard
System smartcard interface: Windows's PC/SC, Linux's PC/SC-lite Manage readers and cards, Transmit ISO7816-4's APDU
Readers Contact: ISO7816-2,3 (T=0/1) Contactless: ISO 14443 (T=CL)
APDU packet
API: EMV, GSM, PIV, OpenPGP, ICAO 9303 (BAC/EAC/SAC) OpenPlatform, ISO7816-4 cmds, custom APDU
Card application 1
n 2
3
SC app programming: JavaCard, MultOS, .NET

APDU (Application Protocol Data Unit)

- APDU is basic logical communication datagram
  - header (5 bytes) and up to ~256 bytes of user data
- Format specified in ISO7816-4
- Header/Data format
  - CLA – instruction class
  - INS – instruction number
  - P1, P2 – optional data
  - Lc – length of incoming data
  - Data – user data
  - Le – length of the expected output data
- Some values of CLA/INS/P1/P2 standardized
- Custom values used by application developer



What values of APDU header are used?

- Standardized values for selected application
  - Improves interoperability
  - https://web.archive.org/web/20180721010834/http://techmeonline.com/most-used-smart-card-commands-apdu/
- Custom commands for proprietary application
  - Your own API

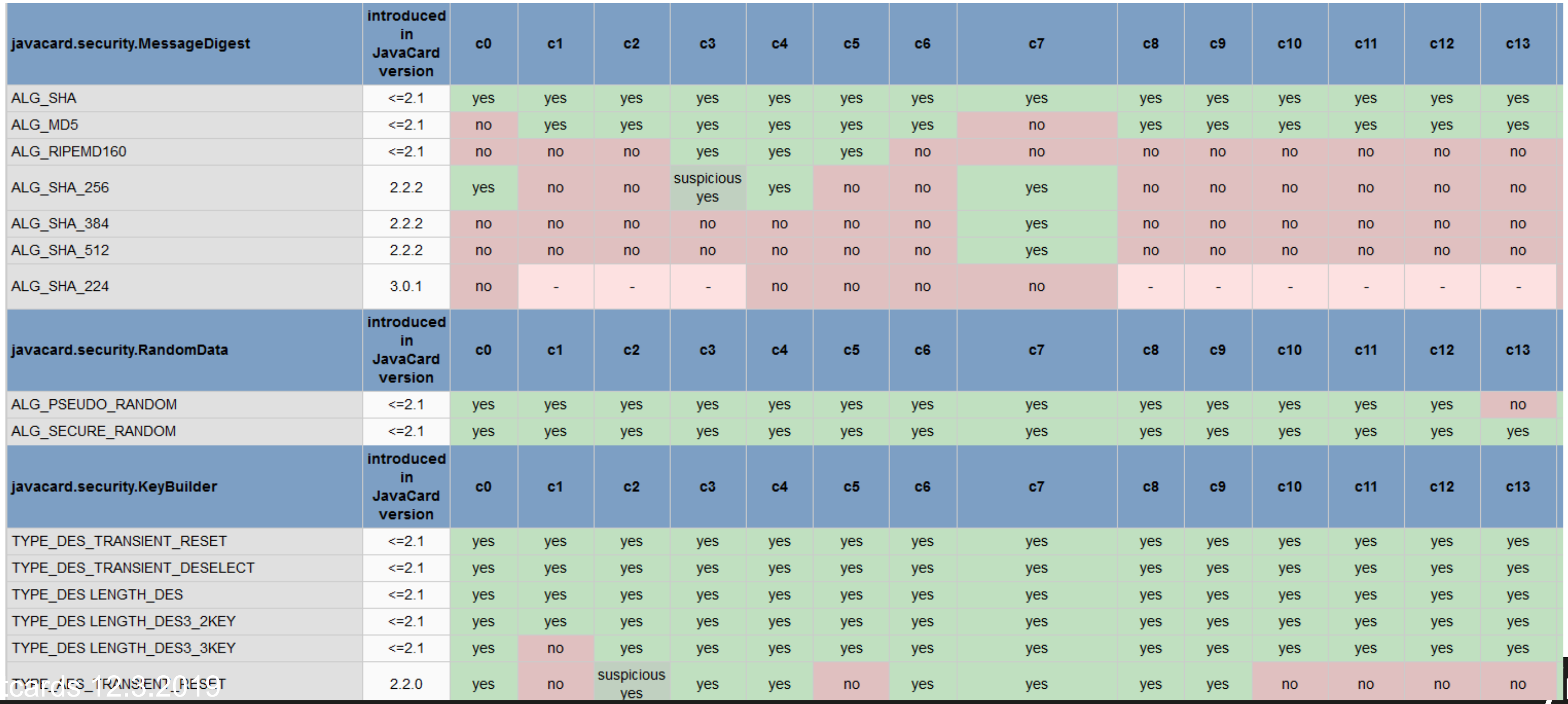
SMARTCARD ALGORITHMS AND PERFORMANCE

Common algorithms

- Basic - cryptographic co-processor
  - Truly random data generator
  - 3DES, AES128/256
  - MD5, SHA1, SHA-2 256/512
  - RSA (up to 2048b common, 4096 possible)
  - ECC (up to 192b common, 384b possible)
  - Diffie-Hellman key exchange (DH/ECDSA)
- Custom code running in secure environment
  - E.g. HMAC, OTP code, re-encryption
  - Might be significantly slower (e.g., SW AES 50x slower)

Cryptographic operations

- Supported algorithms (JCAlgTester, almost 90 cards)
  - https://github.com/crocs-muni/JCAlgTest
  - https://www.fi.muni.cz/~xsvenda/jcsupport.html



javacard.security.MessageDigest	introduced in JavaCard version	c0	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12	c13
ALG_SHA	<=2.1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
ALG_MD5	<=2.1	no	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes
ALG_RIPEMD160	<=2.1	no	no	no	yes	yes	yes	no	no	no	no	no	no	no	no
ALG_SHA_256	2.2.2	yes	no	no	suspicious yes	yes	no	no	yes	no	no	no	no	no	no
ALG_SHA_384	2.2.2	no	no	no	no	no	no	no	yes	no	no	no	no	no	no
ALG_SHA_512	2.2.2	no	no	no	no	no	no	no	yes	no	no	no	no	no	no
ALG_SHA_224	3.0.1	no	-	-	-	no	no	no	no	-	-	-	-	-	-
javacard.security.RandomData	**introduced in JavaCard version**	**c0**	**c1**	**c2**	**c3**	**c4**	**c5**	**c6**	**c7**	**c8**	**c9**	**c10**	**c11**	**c12**	**c13**
ALG_PSEUDO_RANDOM	<=2.1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no
ALG_SECURE_RANDOM	<=2.1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
javacard.security.KeyBuilder	**introduced in JavaCard version**	**c0**	**c1**	**c2**	**c3**	**c4**	**c5**	**c6**	**c7**	**c8**	**c9**	**c10**	**c11**	**c12**	**c13**
TYPE_DES_TRANSIENT_RESET	<=2.1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
TYPE_DES_TRANSIENT_DESELECT	<=2.1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
TYPE_DES LENGTH_DES	<=2.1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
TYPE_DES LENGTH_DES3_2KEY	<=2.1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
TYPE_DES LENGTH_DES3_3KEY	<=2.1	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
TYPE_AES_TRANSIENT_RESET	2.2.0	yes	no	suspicious yes	yes	yes	no	yes	yes	yes	yes	no	no	no	no

What is the typical performance?

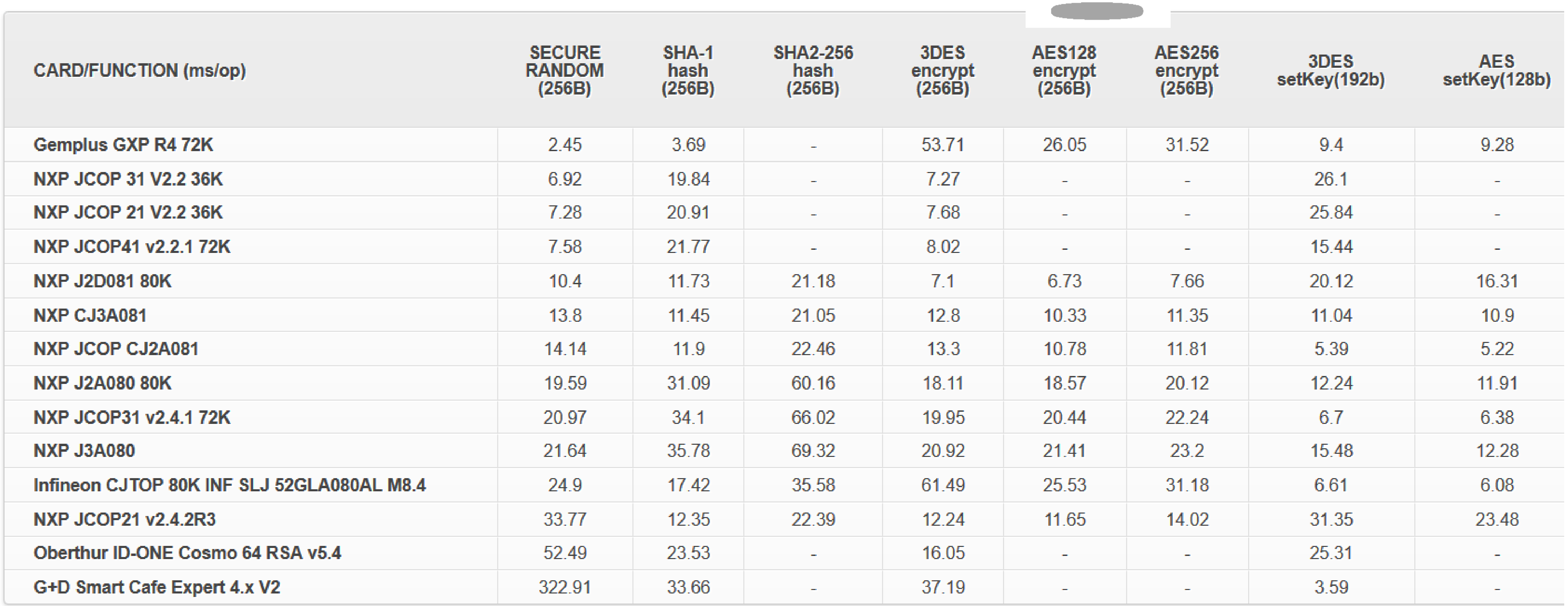
- Hardware differ significantly
  - Clock multiplier, memory speed, crypto coprocessor…
- Typical speed of operation is:
  - Milliseconds (RNG, symmetric crypto, hash)
  - Tens of milliseconds (transfer data in/out)
  - Hundreds of millisecond (asymmetric crypto)
  - Seconds (RSA keypair generation)
- Operation may consists from multiple steps
  - Transmit data, prepare key, prepare engine, encrypt
  - → additional performance penalty

Performance tables for common cards

- Visit https://jcalgtest.org

Is faster always better?

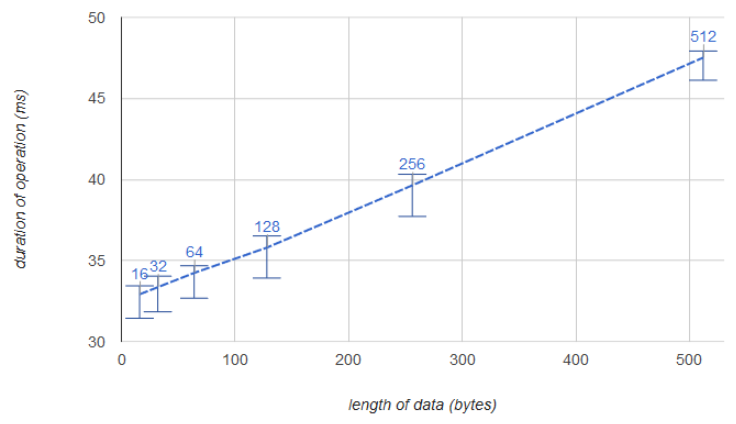
What influences the speed?



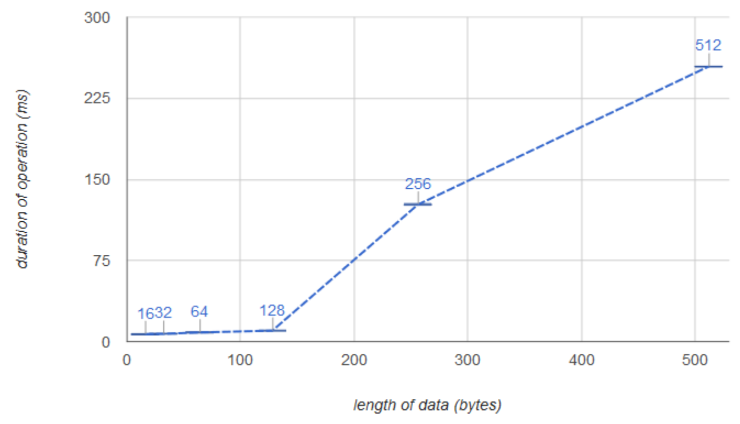
CARD/FUNCTION (ms/op)	SECURE RANDOM (256B)	SHA-1 hash (256B)	SHA2-256 hash (256B)	3DES encrypt (256B)	AES128 encrypt (256B)	AES256 encrypt (256B)	3DES setKey(192b)	AES setKey(128b)
Gemplus GXP R4 72K	2.45	3.69	-	53.71	26.05	31.52	9.4	9.28
NXP JCOP 31 V2.2 36K	6.92	19.84	-	7.27	-	-	26.1	-
NXP JCOP 21 V2.2 36K	7.28	20.91	-	7.68	-	-	25.84	-
NXP JCOP41 v2.2.1 72K	7.58	21.77	-	8.02	-	-	15.44	-
NXP J2D081 80K	10.4	11.73	21.18	7.1	6.73	7.66	20.12	16.31
NXP CJ3A081	13.8	11.45	21.05	12.8	10.33	11.35	11.04	10.9
NXP JCOP CJ2A081	14.14	11.9	22.46	13.3	10.78	11.81	5.39	5.22
NXP J2A080 80K	19.59	31.09	60.16	18.11	18.57	20.12	12.24	11.91
NXP JCOP31 v2.4.1 72K	20.97	34.1	66.02	19.95	20.44	22.24	6.7	6.38
NXP J3A080	21.64	35.78	69.32	20.92	21.41	23.2	15.48	12.28
Infineon CJTOP 80K INF SLJ 52GLA080AL M8.4	24.9	17.42	35.58	61.49	25.53	31.18	6.61	6.08
NXP JCOP21 v2.4.2R3	33.77	12.35	22.39	12.24	11.65	14.02	31.35	23.48
Oberthur ID-ONE Cosmo 64 RSA v5.4	52.49	23.53	-	16.05	-	-	25.31	-
G+D Smart Cafe Expert 4.x V2	322.91	33.66	-	37.19	-	-	3.59	-

Performance with variable data lengths

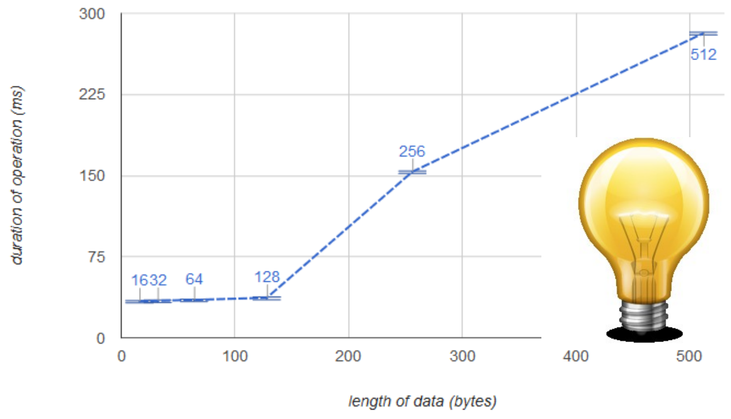
TYPE_DES LENGTH_DES ALG_DES_CBC_NOPAD Cipher_setKeyInitDoFinal()



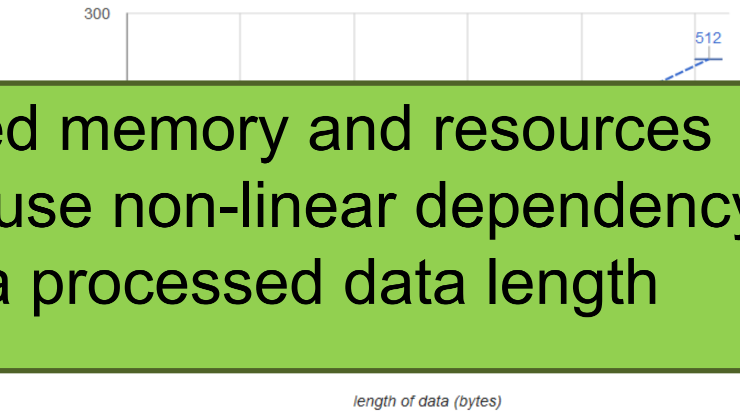
TYPE_DES LENGTH_DES ALG_DES_CBC_ISO9797_M1 Cipher_doFinal()



TYPE_DES LENGTH_DES ALG_DES_CBC_ISO9797_M1 Cipher_setKeyInitDoFinal()

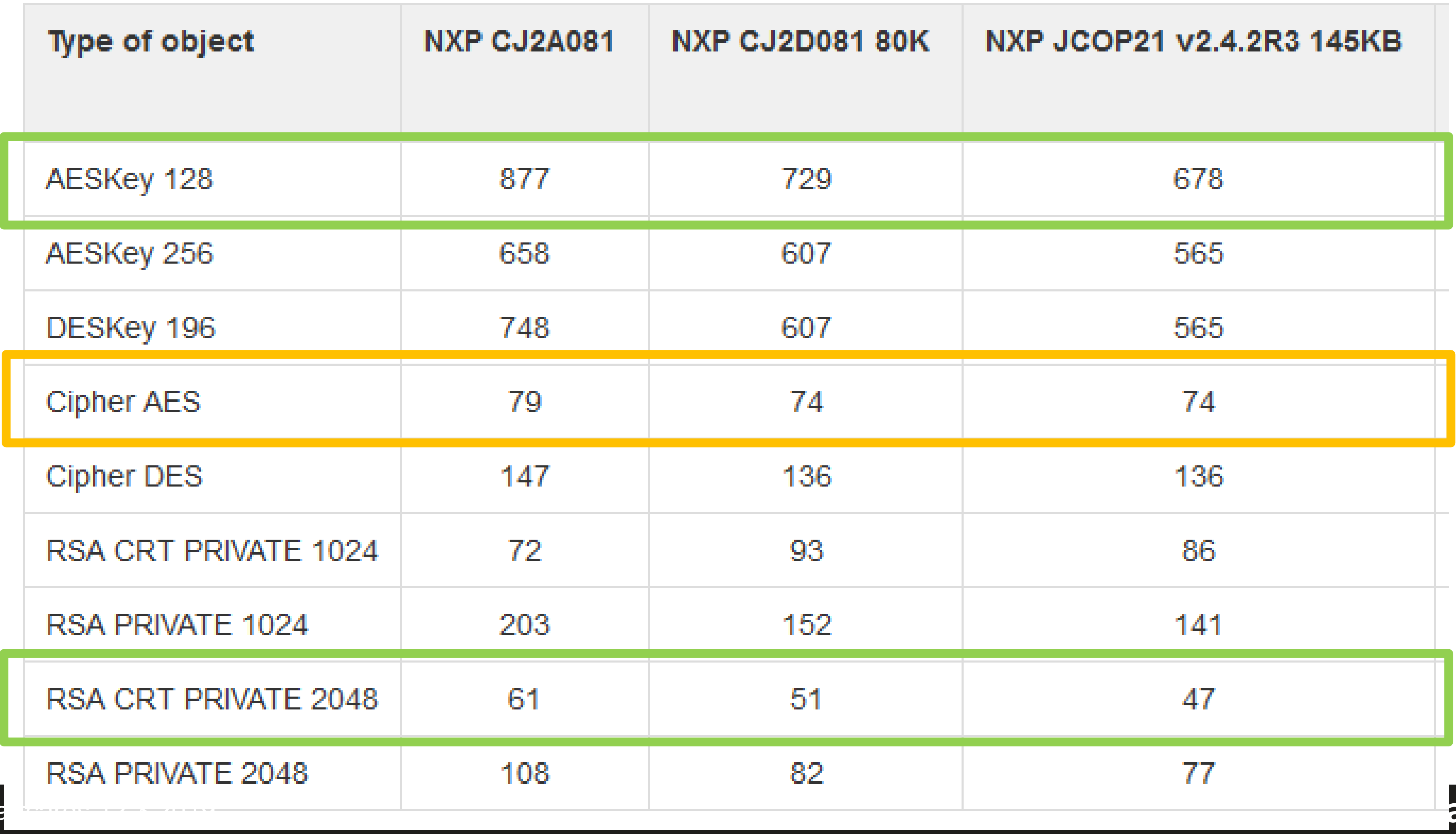


TYPE_DES LENGTH_DES ALG_DES_CBC_ISO9797_M2 Cipher_doFinal()



Limited memory and resources may cause non-linear dependency on a processed data length

How many cryptographic engines?



Type of object	NXP CJ2A081	NXP CJ2D081 80K	NXP JCOP21 v2.4.2R3 145KB
AESKey 128	877	729	678
AESKey 256	658	607	565
DESKey 196	748	607	565
Cipher AES	79	74	74
Cipher DES	147	136	136
RSA CRT PRIVATE 1024	72	93	86
RSA PRIVATE 1024	203	152	141
RSA CRT PRIVATE 2048	61	51	47
RSA PRIVATE 2048	108	82	77

SMART CARD MANAGEMENT

What functionality would require?

Motivation

- How to upload, install and remove applications?
- Who should be allowed to upload/remove apps?
- What if multiple mutually distrusting apps on card?
- How to update application in already issued card?

- Need for cross-platform interoperable standard
  – Many manufactures and platform providers

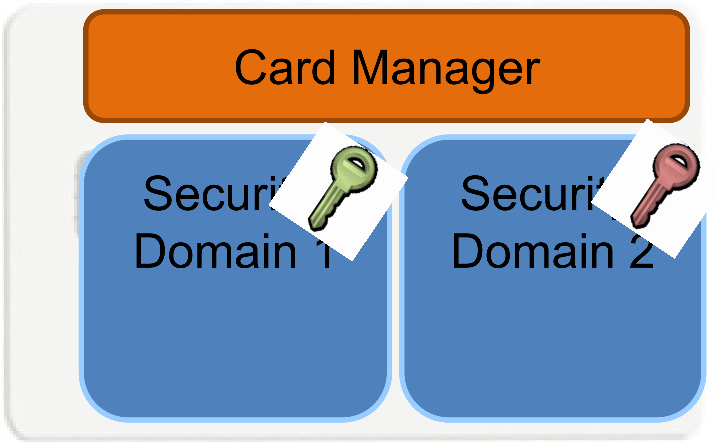
GLOBALPLATFORM

THE STANDARD FOR MANAGING APPLICATIONS ON SECURE CHIP TECHNOLOGY

GlobalPlatform

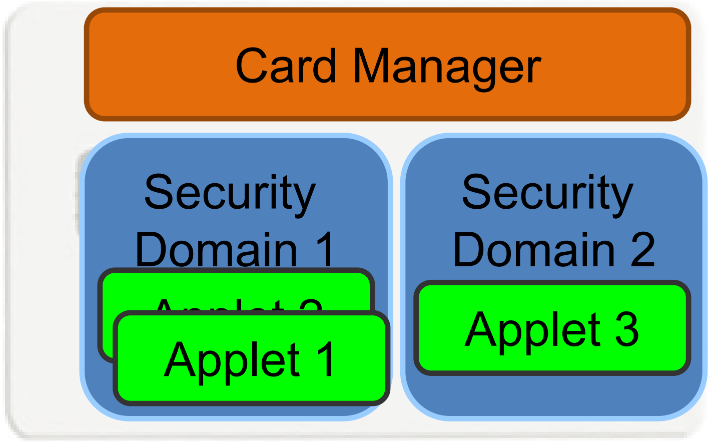
- Specification of API for card administration
  - Upload/install/delete applications
  - Card lifecycle management
  - Card security management
  - Security mechanisms and protocols
- Newest is GlobalPlatform Card Specification v2.3
  - December 2015
  - Previous versions also frequently used
  - http://www.globalplatform.org/specificationscard.asp

GlobalPlatform – main terms



- Smart card life cycle
  - OP_READY, INITIALIZED (prepared for personalization)
  - SECURED (issued to user, use phase)
  - CARD_LOCKED (temporarily locked (attack), unlock to SECURED)
  - TERMINATED (logically destroyed)
- Card Manager (CM)
  - Special card component responsible for administration and card system service functions (cannot be removed)
- Security Domain (SD)
  - Logically separated area on card with own access control
  - Enforced by different authentication keys

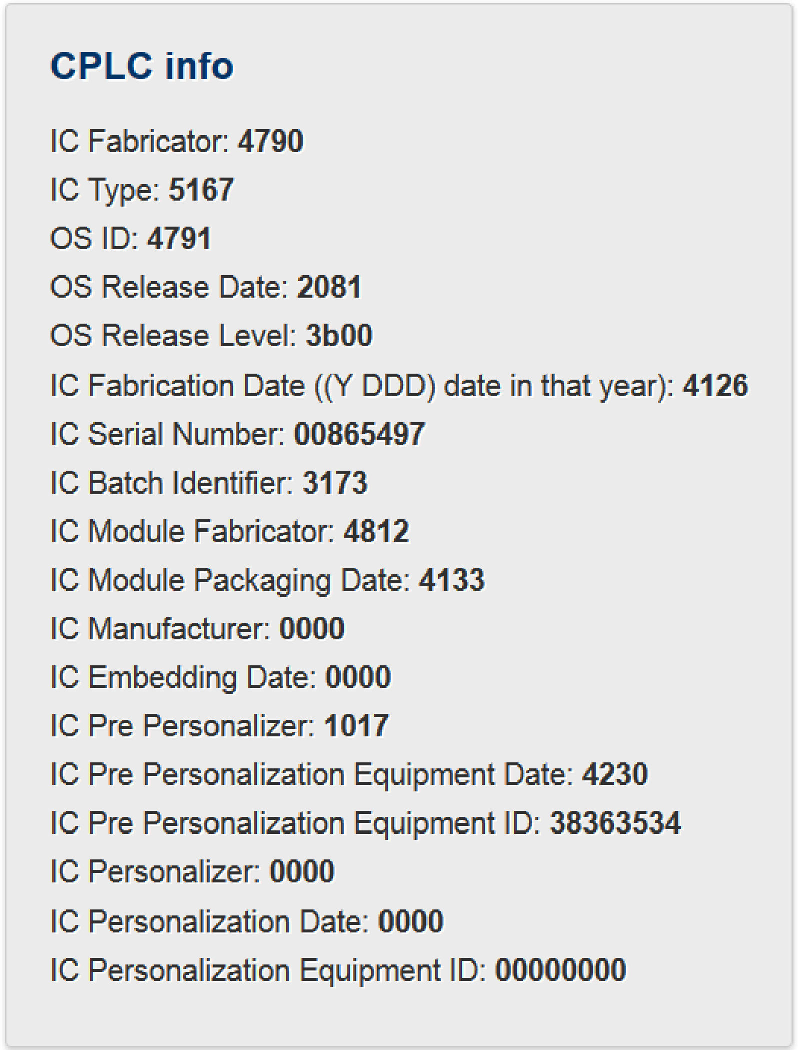
GlobalPlatform – main terms



- Card Content (apps,data) Management
  - Content verification, loading, installation, removal
- Security Management
  - Security Domain locking, Application locking
  - Card locking, Card termination
  - Application privilege usage, Security Domain privileges
  - Tracing and event logging
- Command Dispatch
  - Application selection
  - (Optional) Logical channel management

Card Production Life Cycle (CPLC)

- Manufacturing metadata
- Dates (OS, chip)
- Circuit serial number
- (not mandatory)
- GlobalPlatform APDU
  - 80 CA 9F 7F 00
  - gppro --info
- ISO7816 APDU
  - 00 CA 9F 7F 00



CPLC info

IC Fabricator: **4790**
IC Type: **5167**
OS ID: **4791**
OS Release Date: **2081**
OS Release Level: **3b00**
IC Fabrication Date ((Y DDD) date in that year): **4126**
IC Serial Number: **00865497**
IC Batch Identifier: **3173**
IC Module Fabricator: **4812**
IC Module Packaging Date: **4133**
IC Manufacturer: **0000**
IC Embedding Date: **0000**
IC Pre Personalizer: **1017**
IC Pre Personalization Equipment Date: **4230**
IC Pre Personalization Equipment ID: **38363534**
IC Personalizer: **0000**
IC Personalization Date: **0000**
IC Personalization Equipment ID: **00000000**

TWO FACTOR AUTHENTICATION

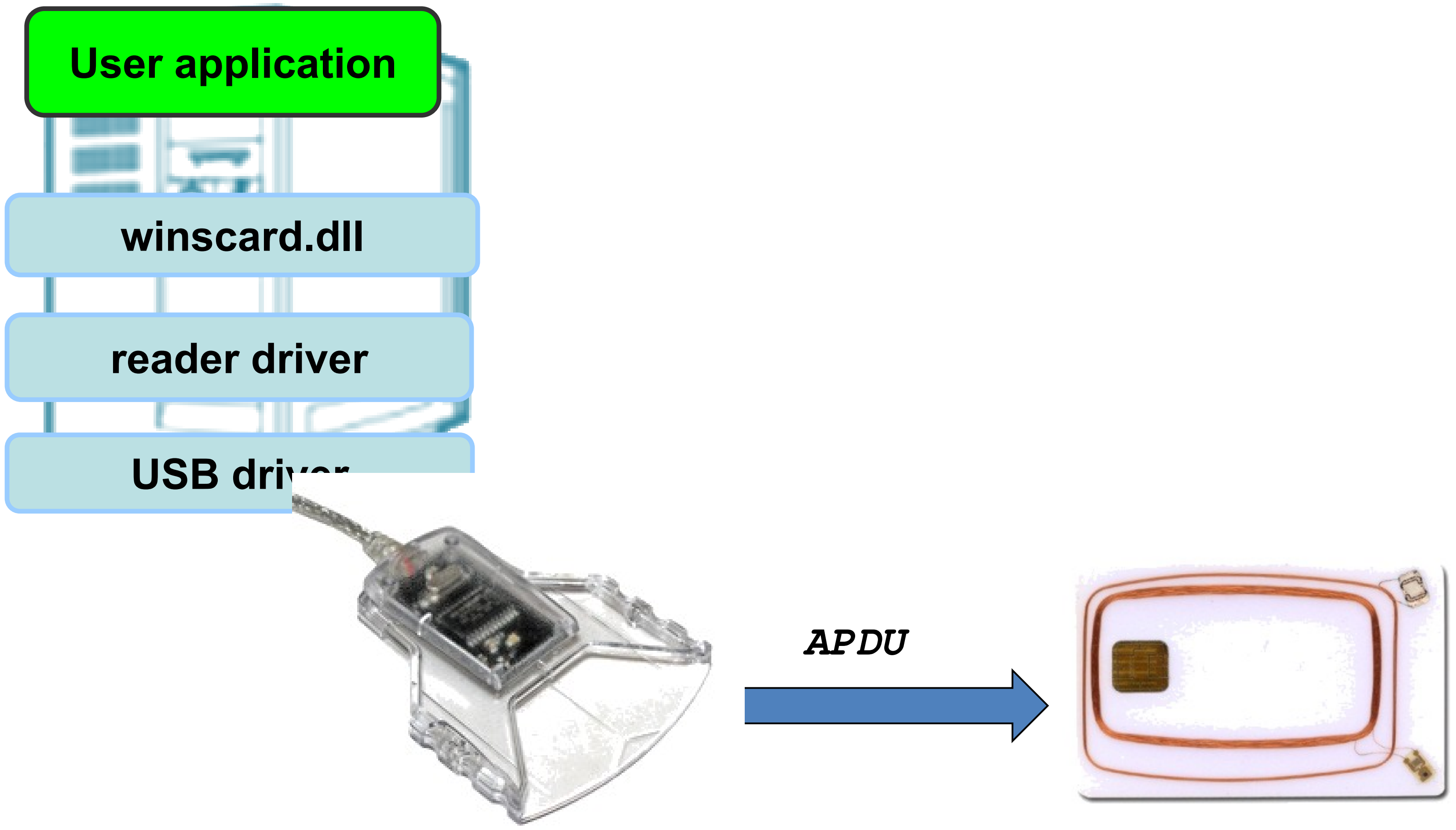
Two-factor authentication

- Two factors with tokens/smart cards
  - Token (smart card, phone) + Knowledge (PIN, Password)

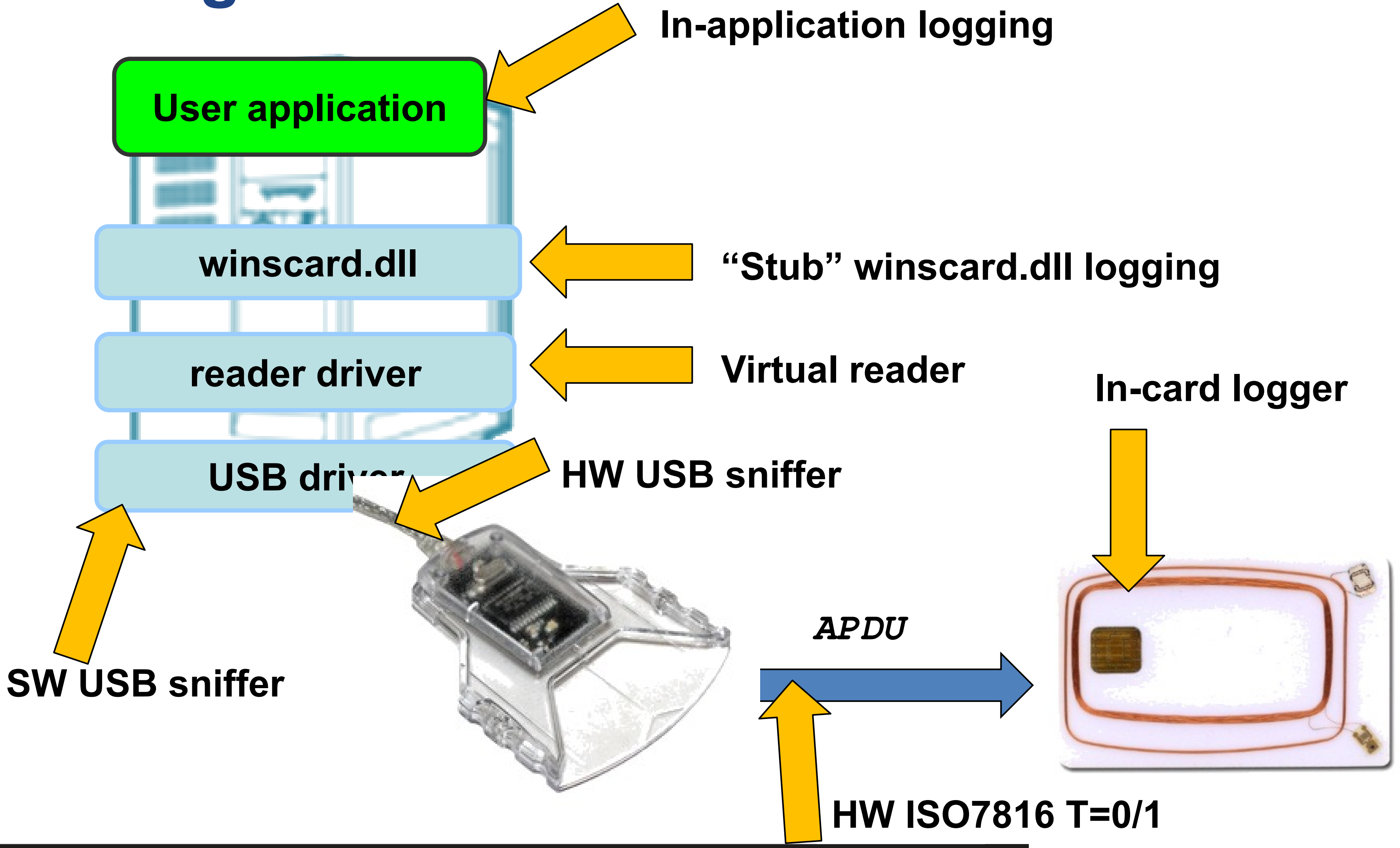
1. Authorize transaction with card and PIN
2. Authenticate with password and SMS
3. Authenticate user with One-Time Password (OTP) generated on mobile phone (stored secret key) after screen unlock (pattern)
4. U2F token (password + token + button press)
5. …

? How to attack two-factor?

Application uses PC/SC interface (SCardxx)

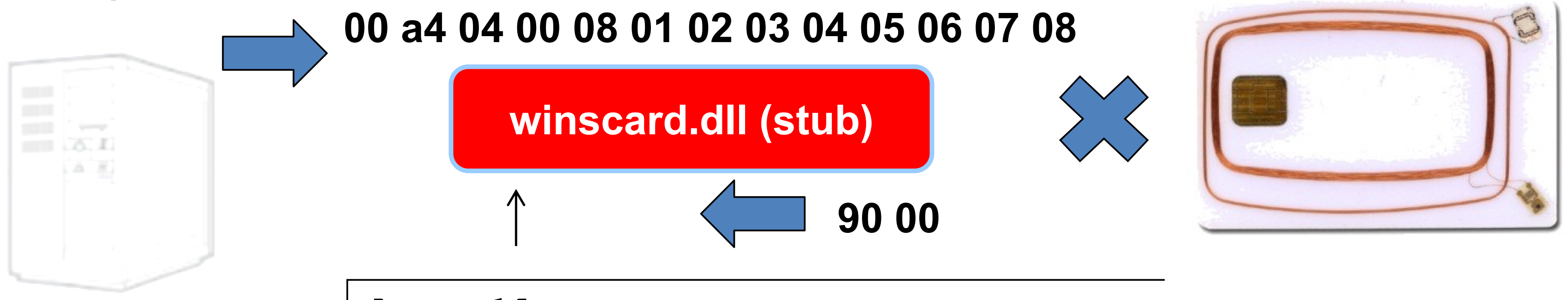


Where to log communication?



For attacking two-factor, logging is usually not enough

- Manipulate incoming/outgoing APDUs
  - modify packet content (change receiver account number)
  - replay of previous packets (pay twice)
  - simulate presence of smart card
  - …



```
[RULE1]
MATCH1=in=1;t=0;cla=00;ins=a4;p1=04;
ACTION=in=0;data0=90 00;le=02;
```

German banking malware (2009)

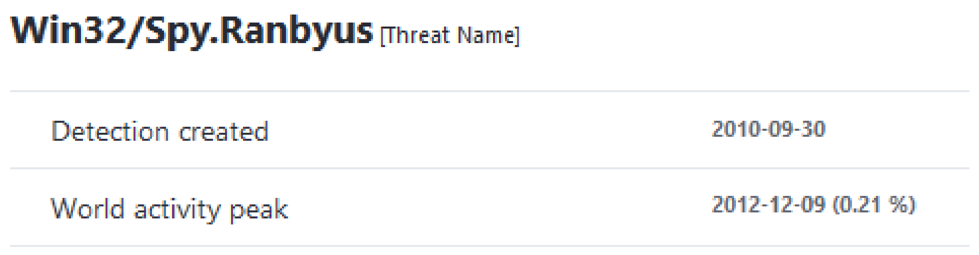
- Two-factor authorization of transactions (chipTAN/cardTAN)
- Application code injection
  - modifies info about transaction and balance shown to user in browser
  - intercepts/modifies transaction data for signature by smart card
  - http://www.cio.com/article/2429854/infrastructure/german-police--two-factor-authentication-failing.html
- The Fairy Tale of "What You See Is What You Sign" - Trojan Horse Attacks on Software for Digital Signatures (2001)
  - http://www.hanno-langweg.de/hanno/research/scits01p.pdf
  - Importance of physical PIN-pad and display of transaction amount independently

German banking malware

User application

Code inject application

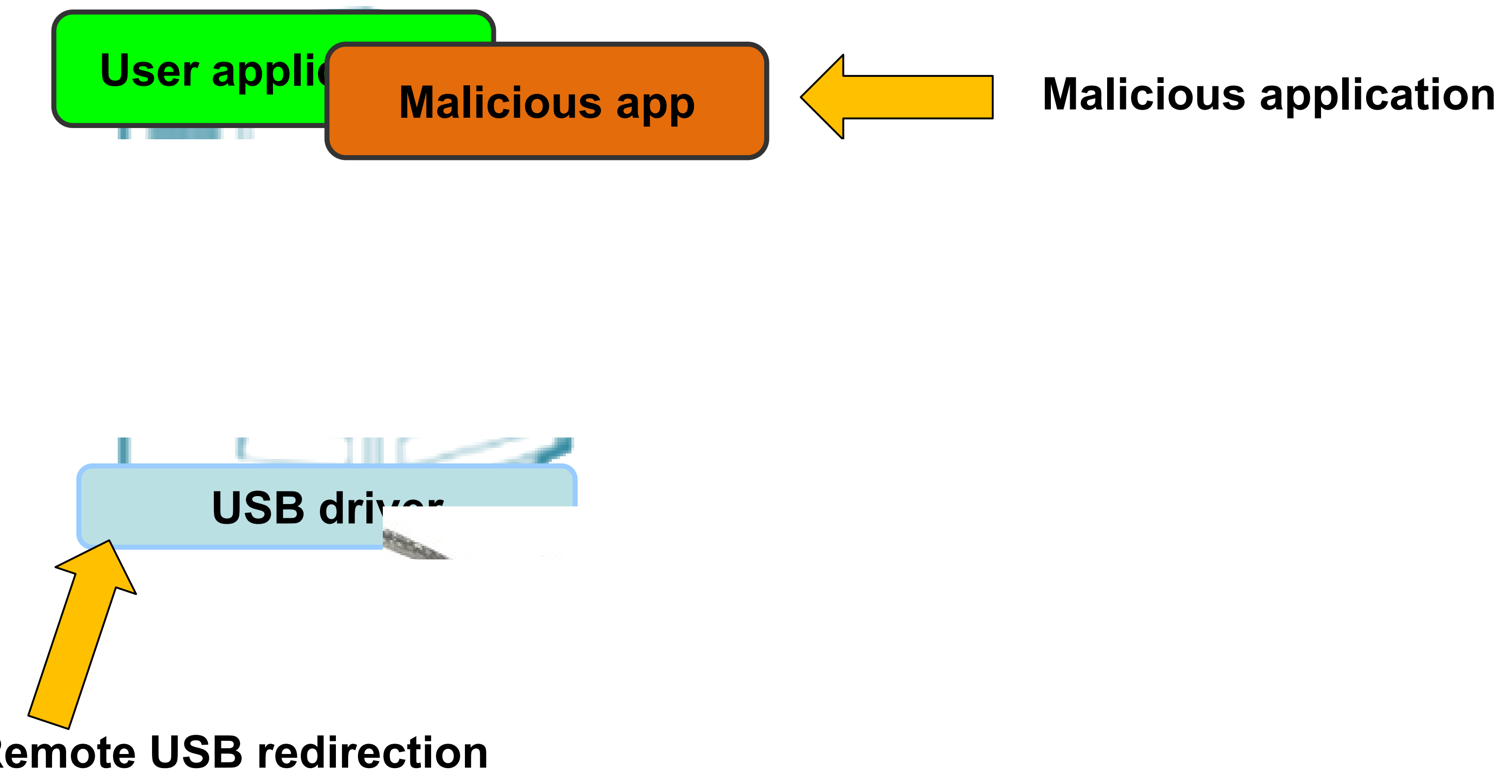
Win32/Spy.Ranbyus


Win32/Spy.Ranbyus [Threat Name]

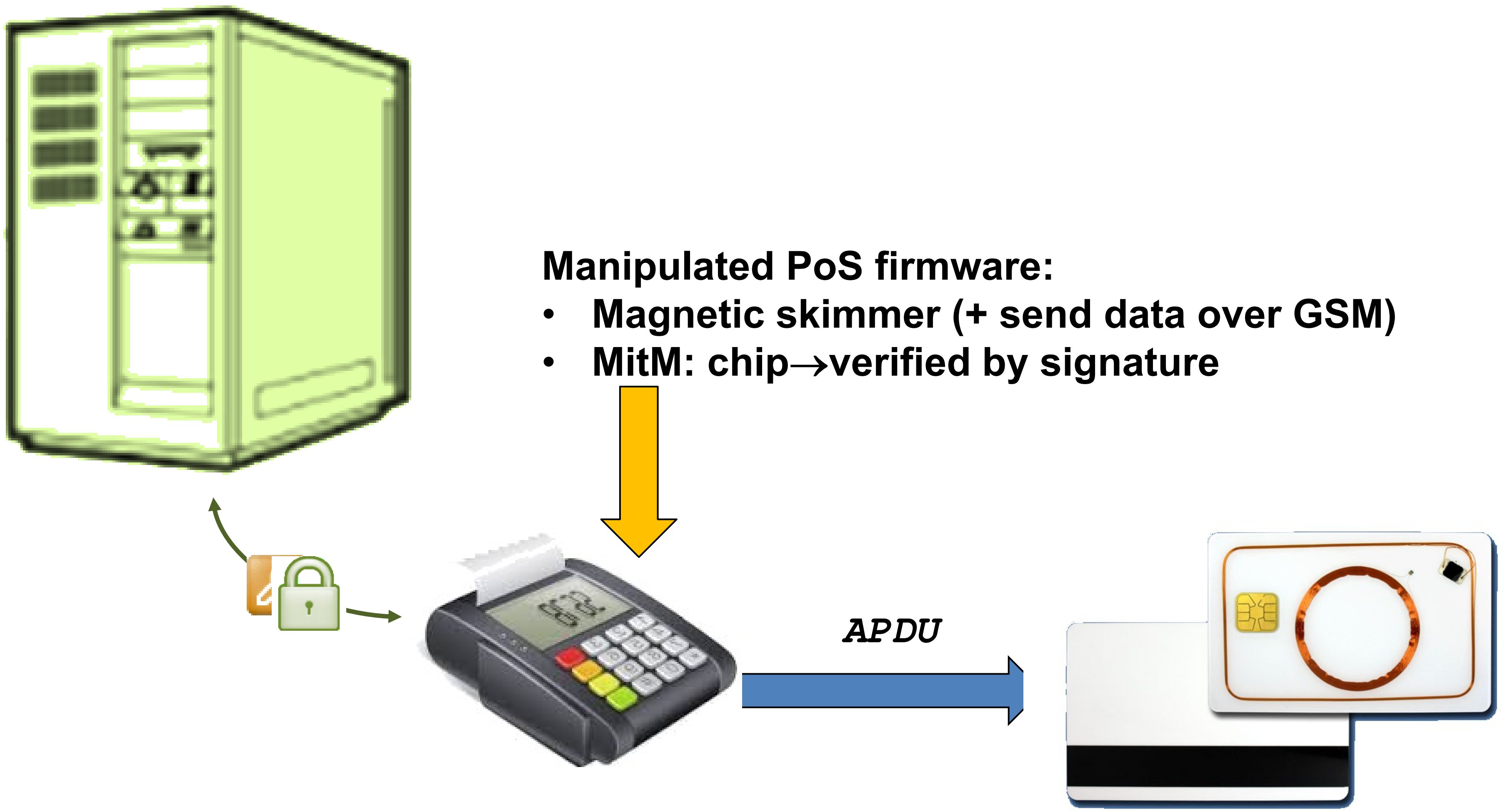
Detection created	2010-09-30
World activity peak	2012-12-09 (0.21 %)

- Analysed by A. Matrosov
  - http://www.welivesecurity.com/2012/06/05/smartcard-vulnerabilities-in-modern-banking-malware/
- Scans for available smart cards, info send to C&C
  - uses PC/SC SmartCard API for scan
  - later redirects communication on USB level (FabulaTech USB for RD installed)

Win32/Spy.Ranbyus



Skimmers, PoS hacks

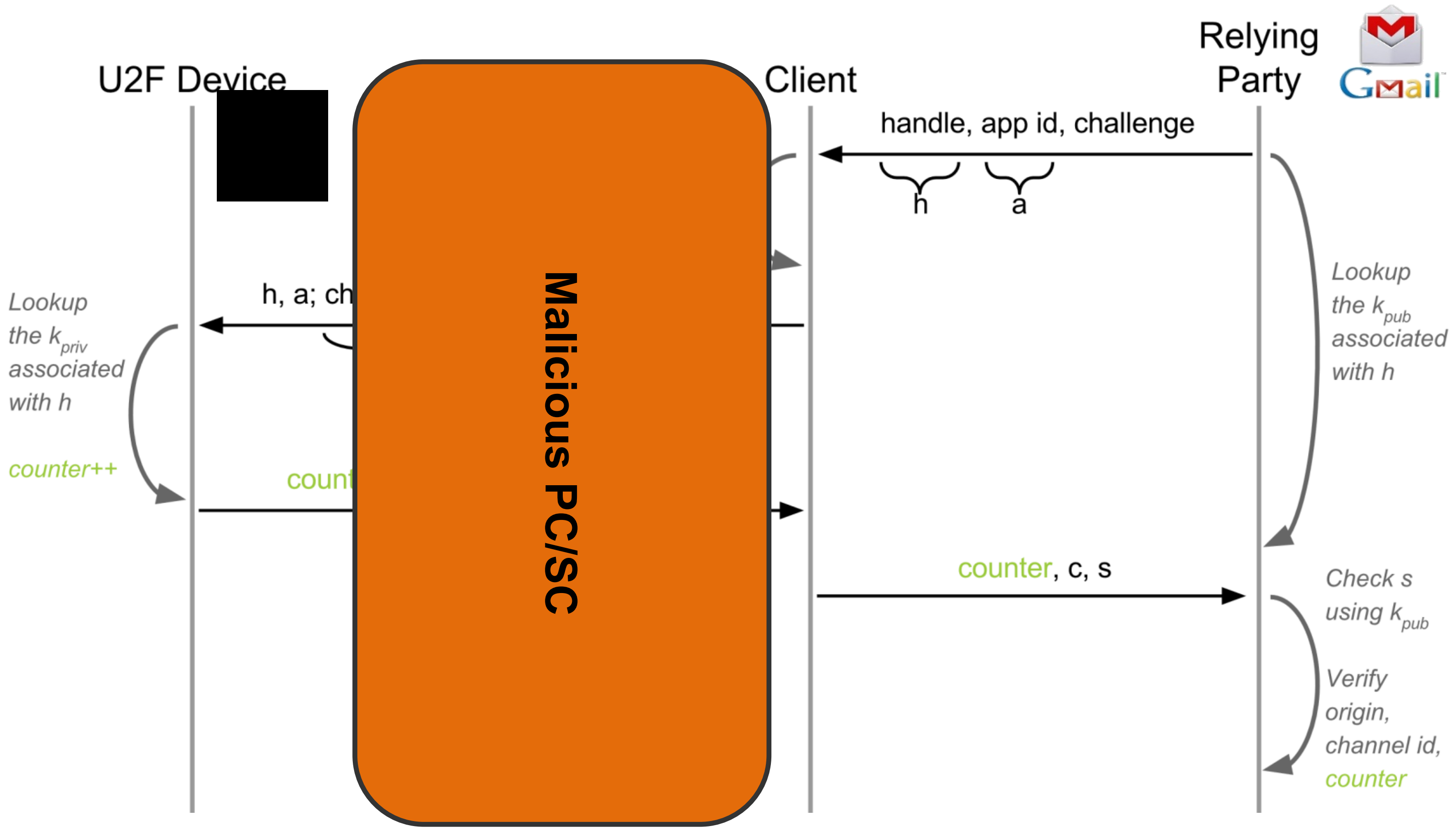


Manipulated PoS firmware:

- Magnetic skimmer (+ send data over GSM)
- MitM: chip$\rightarrow$verified by signature

RECALL U2F
HOW CAN YOU ATTACK U2F IF PC/SC LAYER IS CONTROLLED?

FIDO U2F protocol

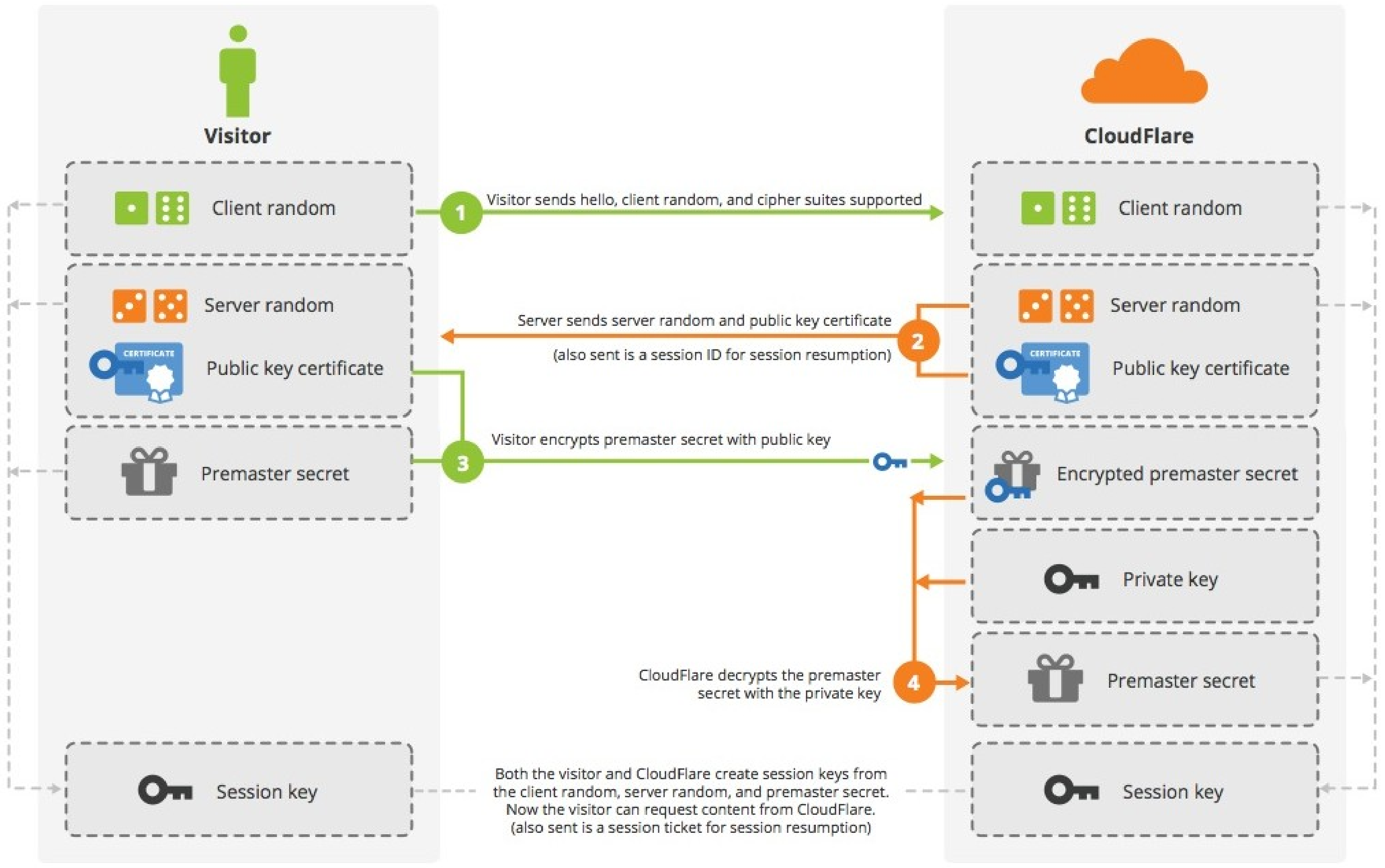

U2F Device
Malicious PC/SC
Client
Relying Party
Gmail
handle, app id, challenge
h
a
h, a; ch
Lookup the k_{priv} associated with h
counter++
count
Lookup the k_{pub} associated with h
counter, c, s
Check s using k_{pub}
Verify origin, channel id, counter

https://developers.yubico.com/U2F/Protocol_details/Overview.html

How to authenticate and communicate securely?

SECURE CHANNEL PROTOCOL (FOR SMARTCARDS)

TLS handshake


Visitor
CloudFlare
Client random
1
Visitor sends hello, client random, and cipher suites supported
Client random
Server random
Public key certificate
Server sends server random and public key certificate
(also sent is a session ID for session resumption)
2
Server random
Public key certificate
Premaster secret
3
Visitor encrypts premaster secret with public key
Encrypted premaster secret
Private key
CloudFlare decrypts the premaster secret with the private key
4
Premaster secret
Session key
Both the visitor and CloudFlare create session keys from the client random, server random, and premaster secret. Now the visitor can request content from CloudFlare. (also sent is a session ticket for session resumption)
Session key

Credit: Cloudflare

Why not to use TLS all the time?

1. Requires asymmetric cryptography
   - Unsuitable for slower devices
2. Requires long keys
   - Unsuitable for devices with small memory
3. Requires significant data overhead (~6.5KB)
   - http://netsekure.org/2010/03/tls-overhead/
4. More lightweight protocols exist
   - RFID / smartcards / IoT…

- Note: TLS can be fully implemented on smartcards (but slow)
  - https://github.com/gilb/smart_card_TLS

Common lightweight SCPs

- OpenPlatform SCP’01,’02 (3DES-based)
- OpenPlatform SCP‘10 (RSA-based)
- OpenPlatform SCP’03 (AES-based)
- ISO/IEC 7816-4 Secure Messaging
- ePassports Basic Access Control (3DES-based)
- ePassports Extended Access Control (3DES,RSA,DH,SHA1/2-based)

Example: GlobalPlatform SCP'03

- Mutual authentication (based on symmetric crypto)
- Session key derivation (based on long-term keys)
  - NIST SP 800-108
- Message (APDU) confidentiality and integrity MAC

1. INITIALIZE UPDATE
   - Random challenge, card's computations
2. EXTERNAL AUTHENTICATE
   - Terminal response
3. Secure messaging

What are problems with usage of symmetric crypto?

Mandatory reading

- When Organized Crime Applies Academic Results
  - A Forensic Analysis of an In-Card Listening Device
  - https://eprint.iacr.org/2015/963.pdf

- Which academic attacks is of concern?
- What system is targeted?
- How is attack carried out? Is it protocol flaw?
- What can prevent this attack vector?

Conclusions

- Smartcards are highly secure and capable modules
  - Programmable
  - Accessible (cost, API…)
- Protocol stack between PC application and smartcard
  - PC/SC, APDU transfer, GlobalPlatform, JavaCard
- Two-factor authentication is not silver bullet
  - But way better than password alone!

Questions