Hardware Security Modules

SecAppDev 2010

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An Atos Origin™ Company

Let’s introduce myself…

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Agenda (1)

- Cryptography: a short history
- HSM
  - Definition
  - Why?
  - Form factors
  - Typical configuration
  - Tamper security
  - Logical security
  - Cryptography
  - Random generators
  - Performance ideas

Agenda (2)

- HSM
  - Development challenges
  - Application areas
  - Key management
  - Standard interfaces/APIs
  - Standards/certifications
  - FIPS 140-2
  - Common Criteria
  - PCI HSM
  - Manufacturers
- Q&A

Cryptography - Short History (1)

- Classical Cryptography
  - 3300 BC, Sumer: first writing system: Cuneiform script

  - 1600 BC, Irak: the oldest cryptographical «document» ever found, a jar!

Cryptography - Short History (2)

- Classical Cryptography
  - 1000 BC, Greece: transposition ciphers (change order of characters) with the scytale (Plutarque’stick)

```
WE ARE DISCOVERED FLEE AT ONCE

W R I O R F E O E
E E S V E L A N J
A D C E D E T C X
```

  - 600 BC, Hebrew: substitution ciphers (change characters)

```
WE ARE DISCOVERED FLEE AT ONCE

VA ZOA RFPBLUAOAR SIAA ZQ LKBA
```

```
ABCDEFGHIJKLMNOPQRSTUVWXYZ
ZEBRASCDFGHIJKLMNOPQTUVWXY
```

Cryptography - Short History (3)

- Classical Cryptography
  - 100 BC, Caesar's ciphers

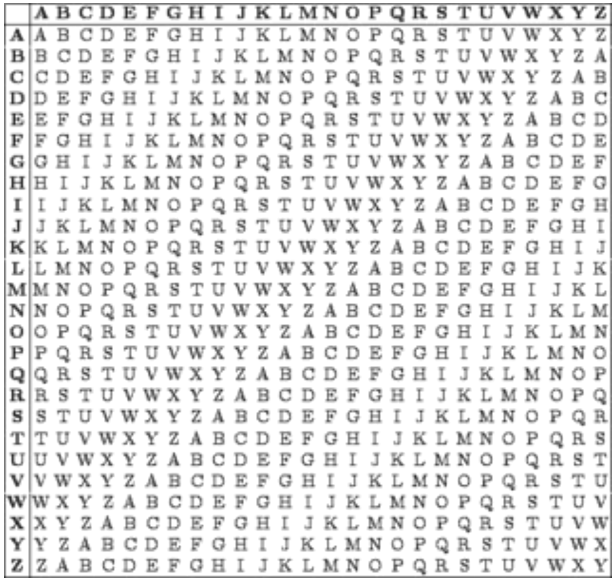
```
WE ARE DISCOVERED FLEE AT ONCE

YG CTG FHUEQXGTF HNGG CV QPEG
```

$$E_n(x) = (x + n) \mod 26.$$
$$D_n(x) = (x - n) \mod 26.$$

  - Medieval, Substitution with multiple substitution alphabets

```
WEAREDISCOVEREDFLEEATONCE
LEMONLEMONLEMONLEMONLEMON
HIMFRO…
```

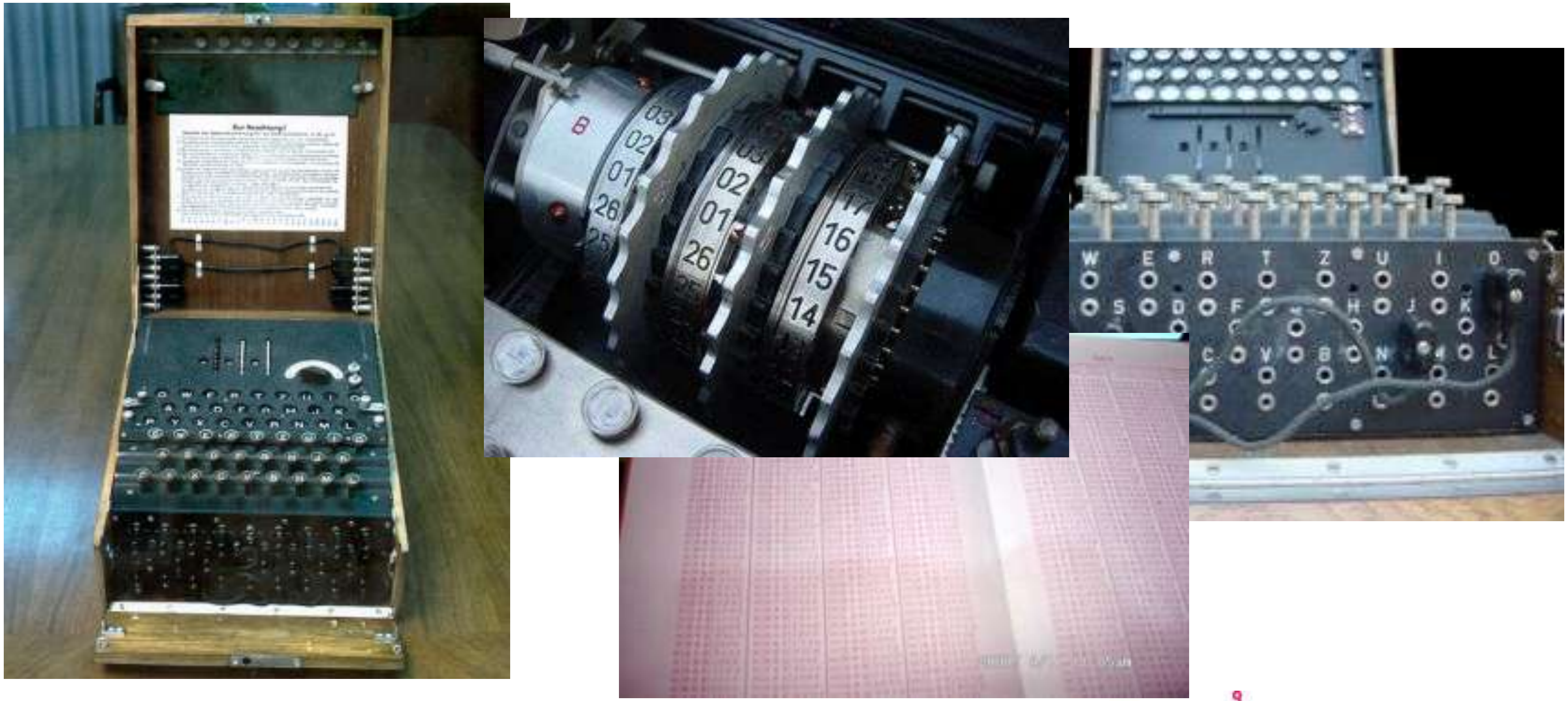


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
B	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A
C	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B
D	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
E	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D
F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
G	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
I	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
J	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
K	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
L	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
M	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
N	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
O	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
P	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
R	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
S	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
T	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
U	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
V	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
W	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
X	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Z	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y

Cryptography - Short History (4)

- Enigma Cipher Machine, 1920, Arthur Scherbius (World War II):

  Polyalphabetic substitution (continually changing substitution alphabet)



Cryptography and HSMs

- What have we learned?

Cryptography uses SECRET keys

- So we need something to protect these keys…

A Hardware Security Module

HSM – Definition (1)

- HSM
  - Hardware Security Module
  - Host Security Module
- Definition
  - Black box combination hardware and software/firmware
  - Attached (or inside) a PC or server
  - Provides cryptographic functions
  - Physical/logical tamper protection (security)
  - (Increased performance)

HSM – Definition (2)

- Purpose
  - (1) Secure generation (and entry)
  - (2) Secure storage (and backup)
  - (3) Secure use (i.e. cryptographic algorithms)
  - Of cryptographic and sensitive data material
  - Note: HSM never allows plaintext key export!
- Other names
  - PCSM – Personal Computer Security Module
  - SAM – Secure Application Module
  - SCD – Secure Cryptographic Device
  - SSCD – Secure Signature Creation Device
  - TRSM – Tamper Resistant Security Module
  - Hardware Cryptographic Device, Cryptographic Module…

HSM – Why?

PERFORMANCE

SECURITY

SECURITY

SECURITY

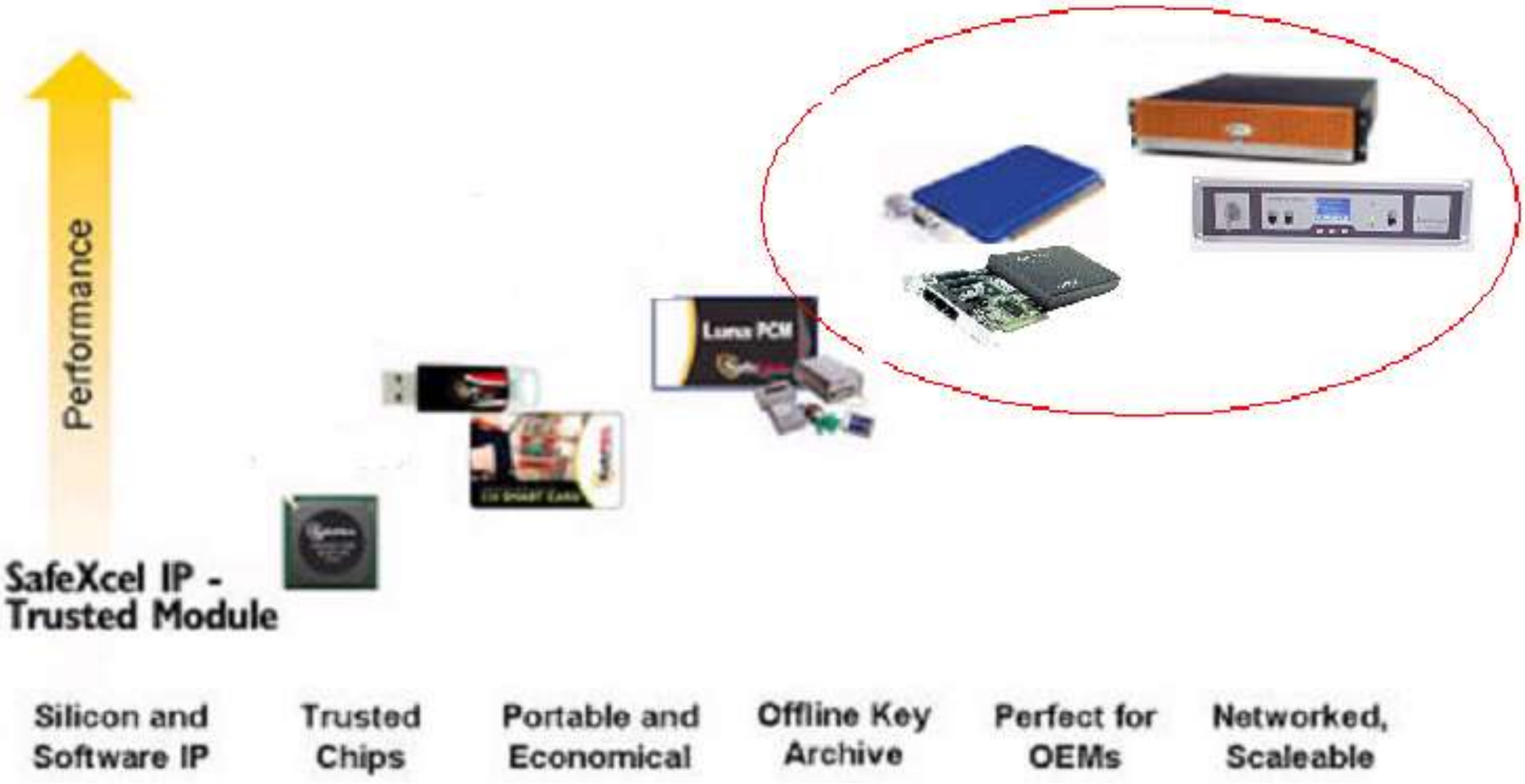
PERFORMANCE

SECURITY

SECURITY

PERFORMANCE

HSM – Form Factors



SafeXcel IP - Trusted Module

Silicon and Software IP

Trusted Chips

Portable and Economical

Offline Key Archive

Perfect for OEMs

Networked, Scaleable

HSM – Definition

- HSM
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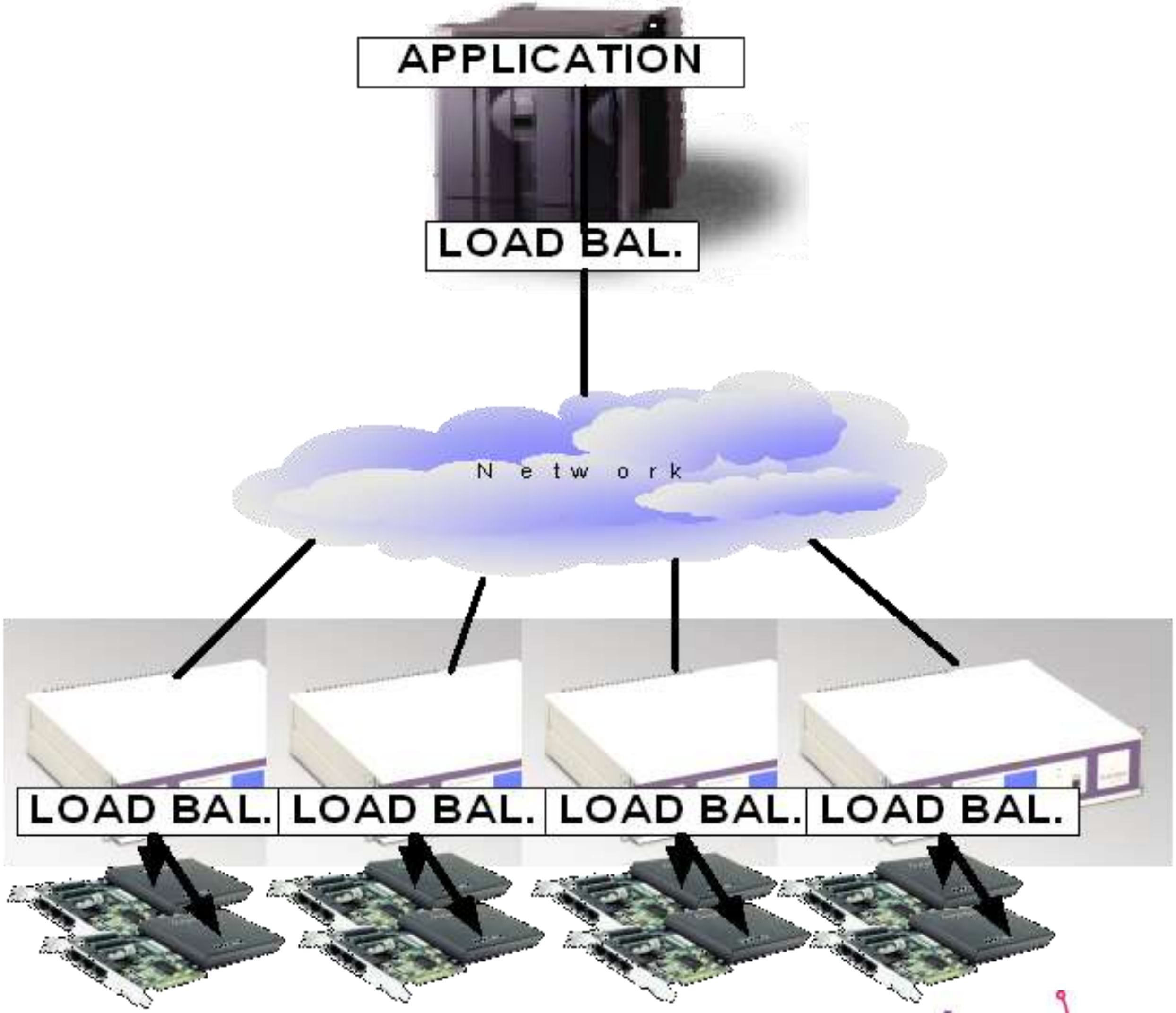
HSM – Typical Configuration (1)



HSM – Typical Configuration (2)

APPLICATION
LOAD BAL.

HSM – Communication Interface

- Internal:
  - PCI Bridge (32 bit / 64 bit)
  - PCI Express
- External:
  - Serial: type RS232
  - Ethernet: from 10 Mbit to 1Gbit
  - USB

HSM – Definition

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HSM – Cryptography (1)

- Cryptography mostly accelerated by hardware accelerators (performance)
- Symmetric cryptography
  - (T)DES, AES
  - Key generation/derivation
  - Encryption/decryption
  - Message Authentication Code
- Asymmetric cryptography
  - RSA, ECC
  - Key generation
  - Data signing (optionally verification)
  - Data decryption

HSM – Cryptography (2)

- Hashing
  - SHA-1, SHA-2, MD5
  - Mostly integrated in other cryptographic functions such as data signing
- Random generator
  - True random generator (Undeterministic)
  - Pseudo random generator (Deterministic)

HSM – Random Generators (1)

- True random generator
  - Undeterministic
  - Uses physical processes which are unpredictable, as far as known (“Noice”), e.g. mouse movements, keyboard input, …
  - (FIPS) outside human control
  - FIPS 140-2: No approved true random number generator
- Pseudo random generator
  - Deterministic
  - Uses computational algorithms (e.g. cryptographic algorithms) that produce long sequences of apparently random results
  - Initiated by a short initial value (“Seed”)
  - E.g. (FIPS 140-2) NIST Recommended Random Number Generator Based on ANSI X9.31 Appendix A.2.4 Using 3-Key Triple DES and AES Algorithms

HSM – Random Generators (2)

- Statistical tests
  - Define the quality of random numbers
- Tests
  - FIPS 140-2
    - Undeterministic: no approved
    - Deterministic: known-answer-tests (KAT)
  - Diehard measures quality of set of random numbers

HSM – Definition

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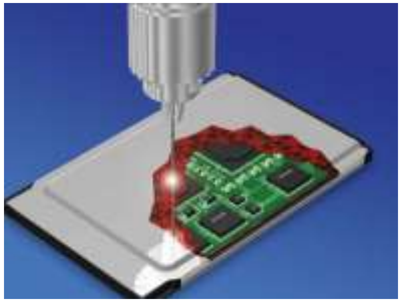
HSM – Tamper Security (1)

- Tamper security terminology
  - Tamper Evidence
    - Unauthorised access to the protected object is easily detected
    - E.g. tamper seals, tamper stickers
  - Tamper Detection and Responsiveness
    - Automatic action by the protected object when a tamper has been detected (Tamper Detection) by the protected object itself
    - E.g. temperature sensors
  - Tamper Resistance
    - Resistance to tampering by normal users or others with physical access to the protected object
    - E.g. special screws

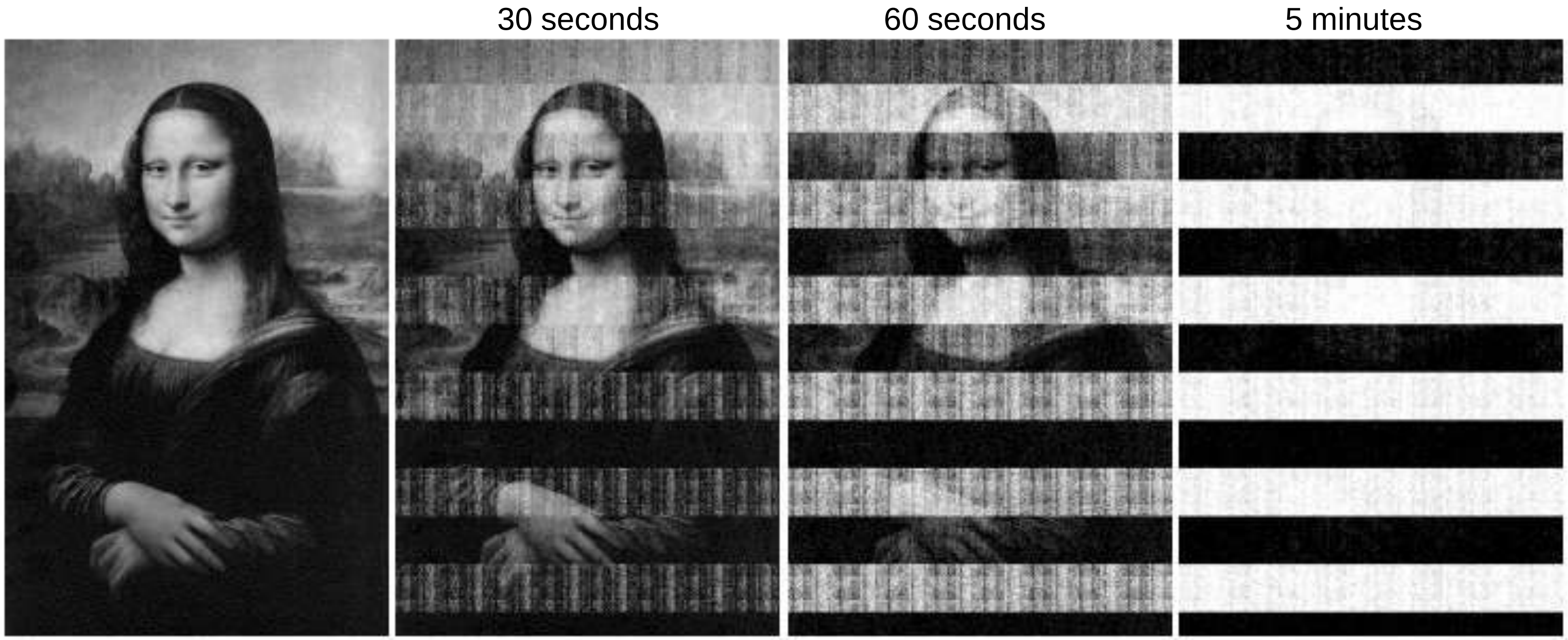
HSM – Tamper Security (2)



- Tamper security in HSM
  - Opaque epoxy
  - Wiring
    - Detection of mechanical penetration
    - Detection of chemical penetration
  - Temperature manipulation
    - Low: freezing (liquid nitrogen) memory attack
    - High: guarantee correct working
  - Battery manipulation
  - Power Supply (Voltage) variation
  - Movement
  - Light sensors

HSM – Tamper Security (3)

- Data Remainance



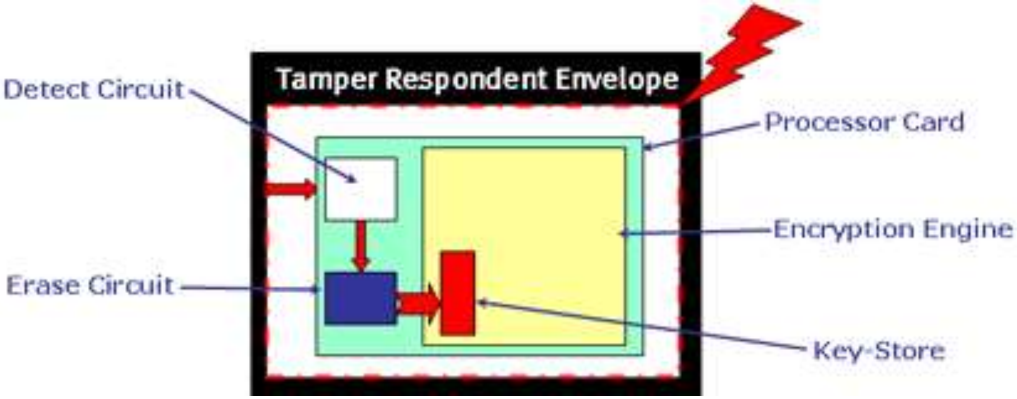
30 seconds

60 seconds

5 minutes

HSM – Tamper Security (4)

- Zeroization
  - Definition: erase sensitive data and secret keys after Tamper Detection
  - Data remainance: residual representation of data that has been in some way nominated erased or removed
  - HSM requires active erasure of all memory containing sensitive data and secret keys
    - Fast!
    - Overwrite memory: zeroes, random or combination



HSM – Logical Security (1)

- Software/Firmware update: integrity and authentication
- Access control: grant access to functions with
  - Count limit
  - Time limit
  - No limit
- Real time clock: accuracy
- Communication: host authentication
- Logical HSM partitions
- Audit trails

HSM – Logical Security (2)

- Side Channel Attacks: attacks based on side channel information
  - Timing Attacks: based on measuring the time it takes for the HSM to perform an operation
  - Power Consumption Attacks: attacks based on analyzing the power consumption of the HSM during encryption operations
    - SPA (Single Power analysis): visual representation of the power consumption
    - DPA (Differential Power Analysis): statistical analysis of the power consumption
  - Fault Analysis Attacks: investigate ciphers and extract keys by generating faults

HSM – Definition

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  - Host Security Module
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  - Black box combination hardware and software/firmware
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  - Physical/logical tamper protection (security)
  - (Increased performance)

HSM – Performance Ideas

- Almost no public information available
  - Internal versus external
  - Cryptographic module versus ethernet box
  - Asynchronous or synchronous
  - No raw cryptography
  - Optimal situations
- RSA 1024 bit Private Key operation: 100 – 7000 operations/second
- ECC 160 bit ECDSA signatures: 250 – 2500 operations/second
- 3DES: 2 - 8 Mbytes/second
- AES: 6 - 40 Mbytes/second (256 bit key)

HSM – Development Challenges

- Physical Security versus Performance versus Power Dissipation
  - Hardware accelerators
  - Performant processors with low power consumption
  - Potting
- Tamper Responsiveness
  - Intrusion Detection
  - Instant Zeroisation
- Separation of non-security and security parts
  - Hardware separation: different processors, memories, …
  - Logical separation: e.g. « sandboxing »
- Side-Channel Attacks versus Performance versus Cryptographic algorthms
  - Hardware (constant power supply) and logical protection
  - Logical protection impacts performance

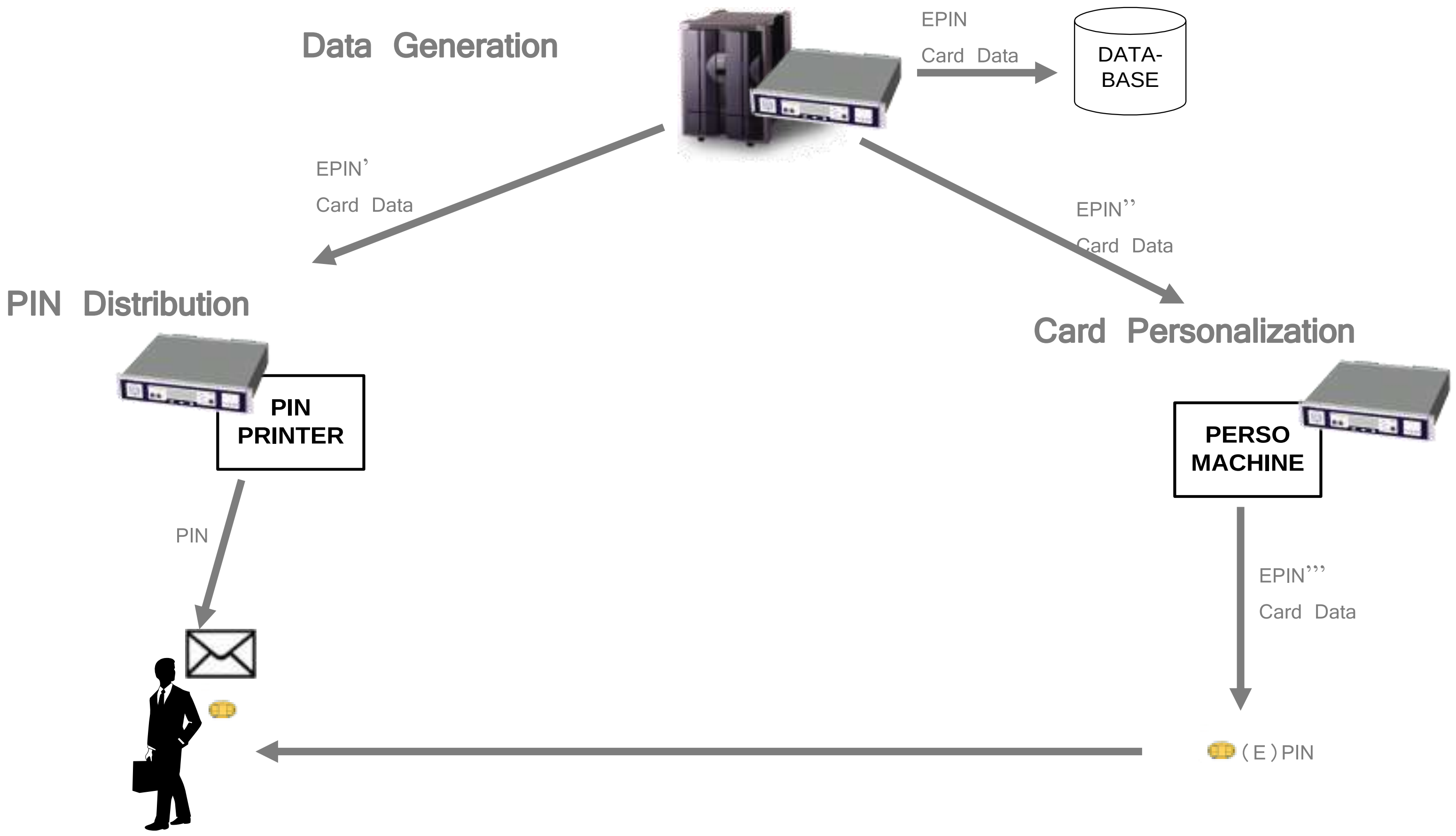
HSM – Application Areas (1)

- PKI Environments
  - Certification Authority (CA) and Registration Authority (RA)
  - Generate, store and handle key pairs
- Card Payment Systems
  - Authentication and integrity checking of messages
  - Confidentiality (e.g. PIN)
  - On-line PIN verification
  - Checking card security codes
  - Re-encryption of PIN blocks
  - Card creation: PIN mailers, generation of magnetic stripe data, personalization of chip cards
  - E-commerce and M-commerce
  - Home banking

HSM – Application Areas (2)

- Others
  - Key Distribution Centers
  - SSL connectivity
  - PayTV
  - Access control: one time passwords, user authentication
  - (Qualified) Digital signatures
  - Time-stamping
  - Trusted Platform Modules (TPM)
  - Document protection
  - Army

HSM – Application Areas: Card Production



Data Generation

EPIN

Card Data

DATA-BASE

EPIN'

Card Data

EPIN''

Card Data

PIN Distribution

PIN PRINTER

Card Personalization

PERSO MACHINE

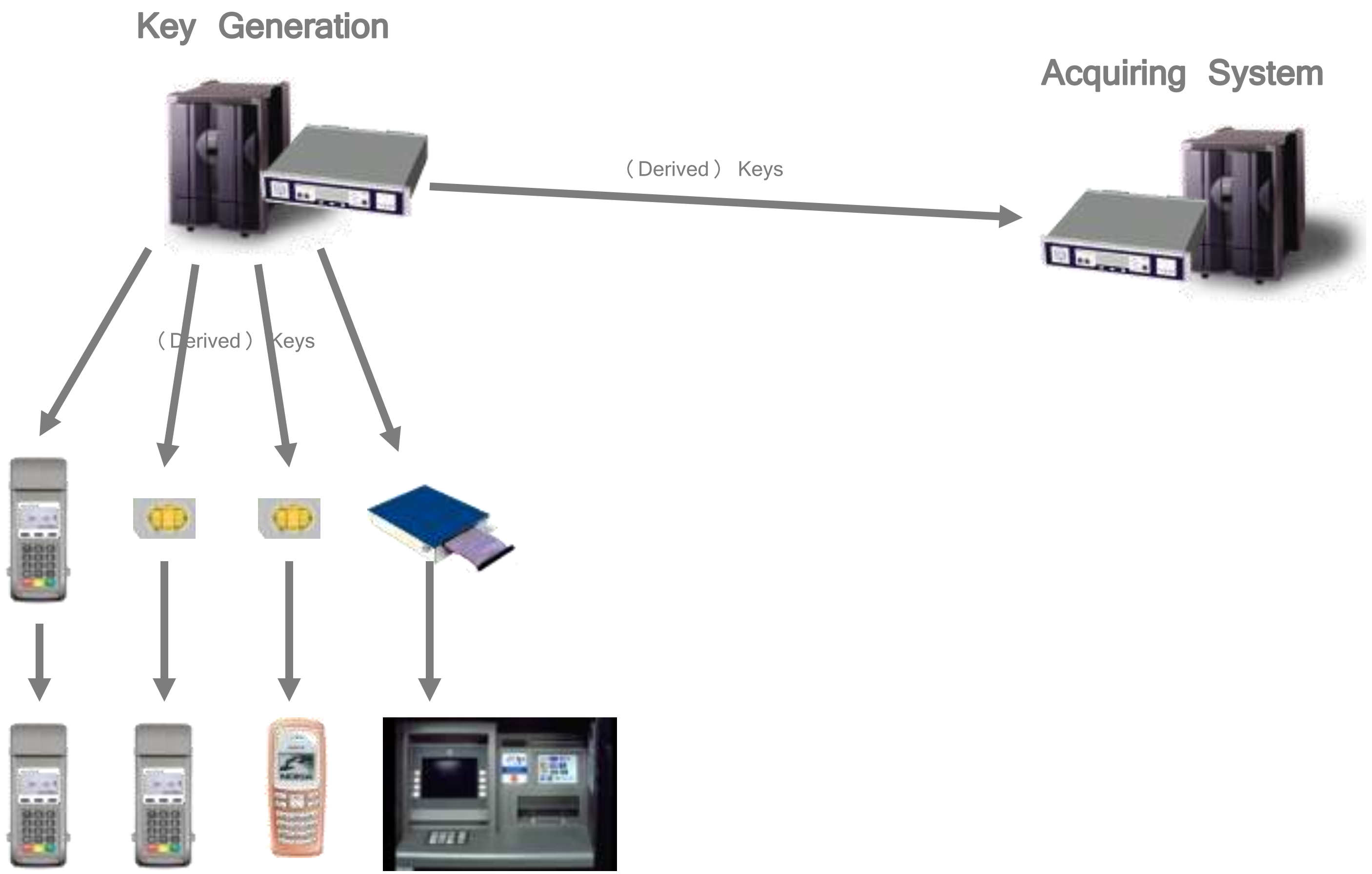
PIN

EPIN'''

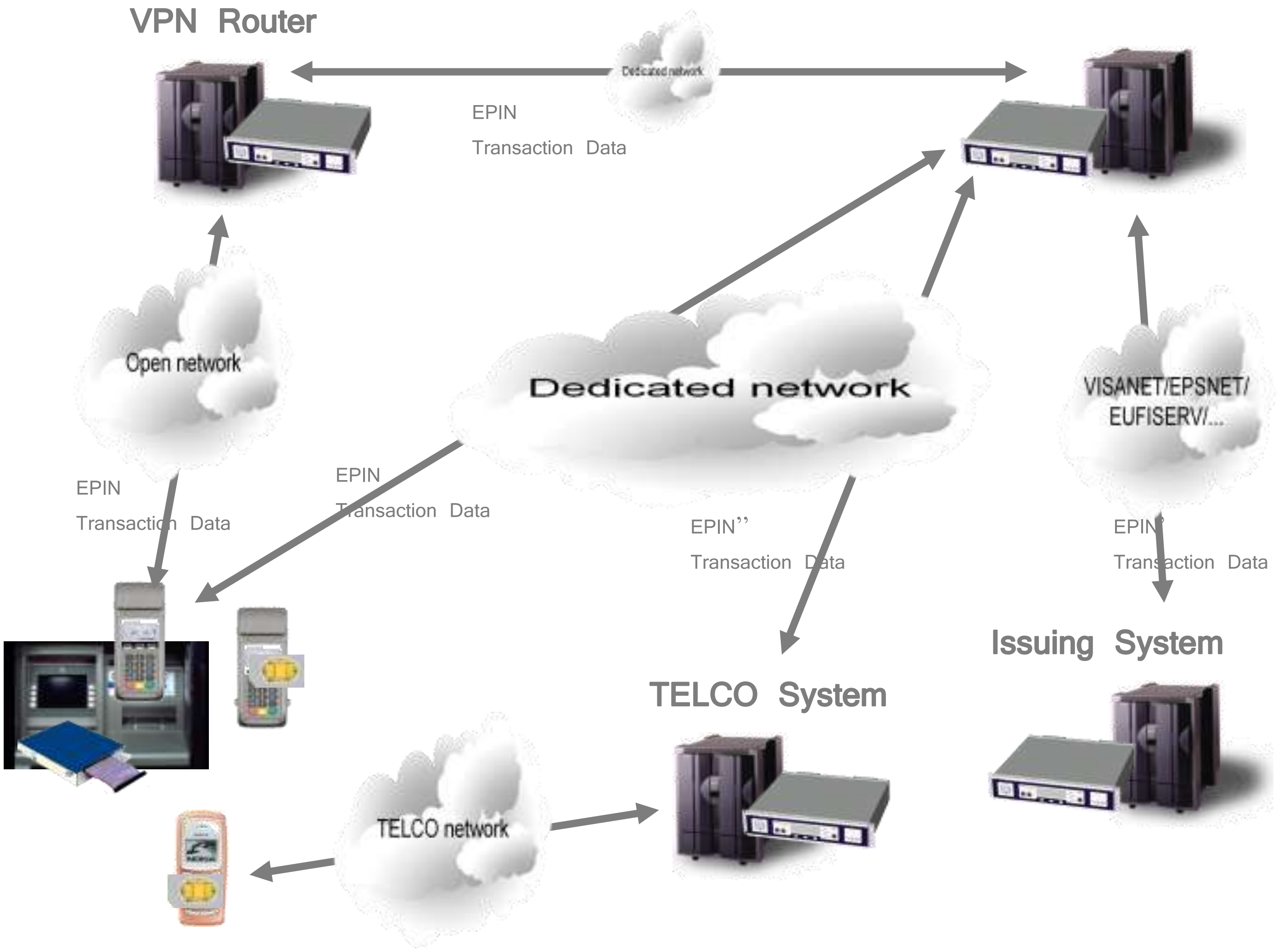
Card Data

(E) PIN

HSM – Application Areas: Key Distribution



HSM – Application Areas: Card Payment



VPN Router

Dedicated network

EPIN

Transaction Data

Open network

Dedicated network

VISANET/EPSNET/ EUFISERV/...

EPIN

Transaction Data

EPIN

Transaction Data

EPIN’’

Transaction Data

EPIN’

Transaction Data

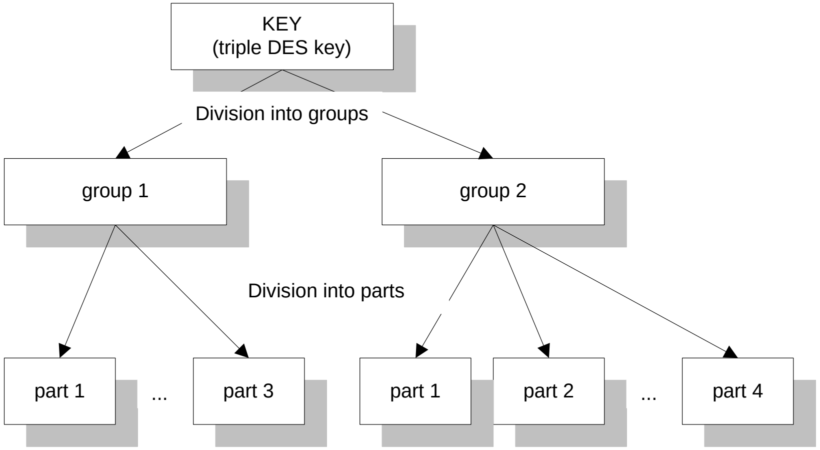
Issuing System

TELCO System

TELCO network

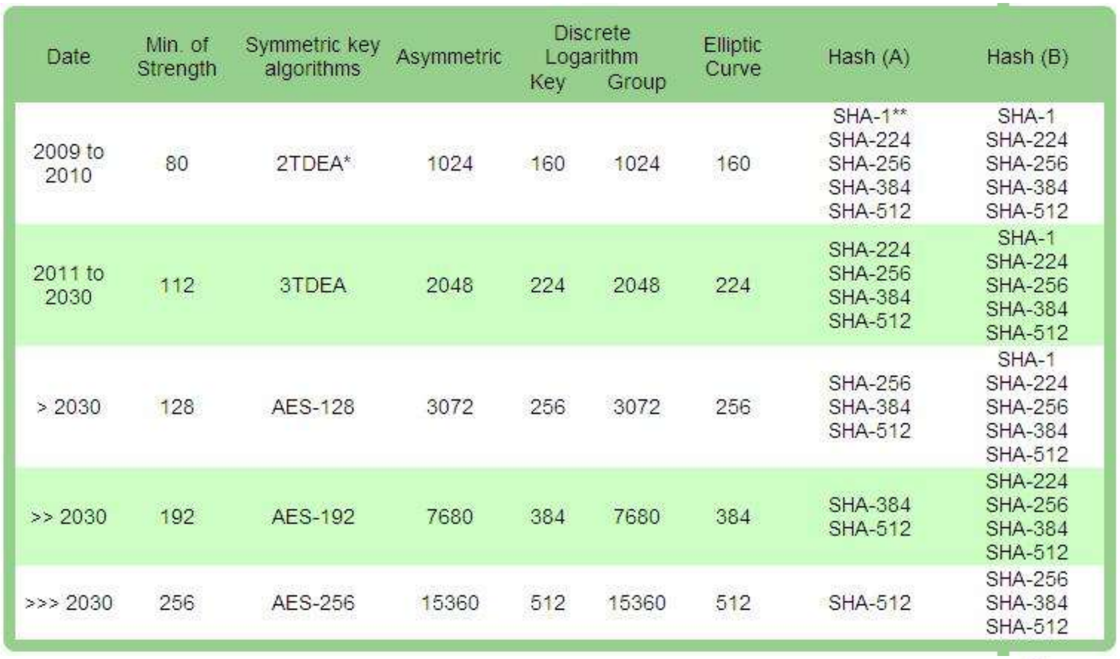
HSM – Key Management (1)

- ISO-11770: Information Technology – Security Techniques - Key Management
- Key generation (random generation!!):
  - Cleartext keys stored inside HSM protected memory («key storage»)
  - Special key properties:
    - (T)DES: weak/semi-weak keys and parity bits!
    - RSA: prime number generation, output Public Key
  - Output for key exchange:
    - Key components (XOR2/XOR3)
    - Secret sharing
    - Key cryptogram (transport key)
- (Manual) key entry
    - Key components (XOR2/XOR3)
    - Secret sharing
    - Key cryptogram (transport key)



HSM – Key Management (2)

- Key storage/backup
  - Key space backup: backup of complete key space guaranteeing the confidentiality and integrity of the whole backup
  - Individual key storage: cryptograms with confidentiality & integrity protection



Date	Min. of Strength	Symmetric key algorithms	Asymmetric	Discrete Logarithm		Elliptic Curve	Hash (A)	Hash (B)
				Key	Group			
2009 to 2010	80	2TDEA*	1024	160	1024	160	SHA-1** SHA-224 SHA-256 SHA-384 SHA-512	SHA-1 SHA-224 SHA-256 SHA-384 SHA-512
2011 to 2030	112	3TDEA	2048	224	2048	224	SHA-224 SHA-256 SHA-384 SHA-512	SHA-1 SHA-224 SHA-256 SHA-384 SHA-512
> 2030	128	AES-128	3072	256	3072	256	SHA-256 SHA-384 SHA-512	SHA-1 SHA-224 SHA-256 SHA-384 SHA-512
>> 2030	192	AES-192	7680	384	7680	384	SHA-384 SHA-512	SHA-224 SHA-256 SHA-384 SHA-512
>>> 2030	256	AES-256	15360	512	15360	512	SHA-512	SHA-256 SHA-384 SHA-512

HSM – Key Management (3)

- Key management devices: direct connection to cryptographic hardware (trusted path)

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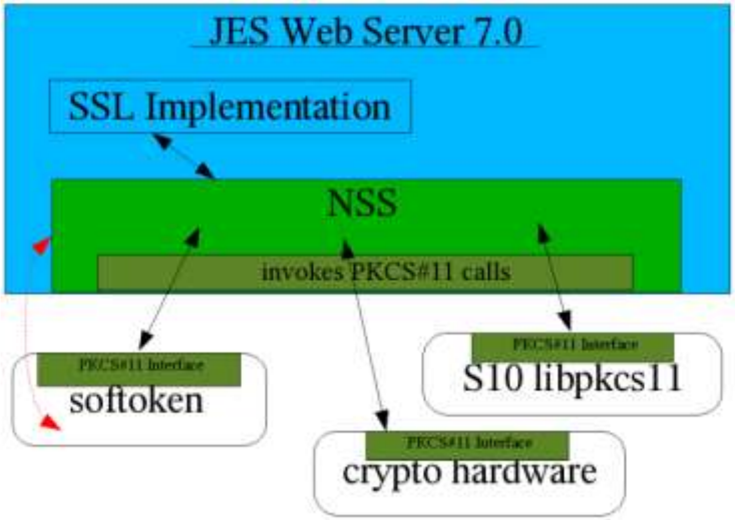
HSM – Standard Interfaces/API

- Standard API defining generic interfaces to cryptographic tokens (e.g. HSM)
- Goal: applications independent from HSMs
- Interfaces:
  - PKCS #11 (Public Key Cryptography Standards) (also «cryptoki»)
  - MSCAPI (Microsoft Cryptography API
  - JCE (JAVA Cryptographic Engine)
- Examples of applications using PKCS#11:
  - Mozilla Firefox/Thunderbird
  - OpenSSL
  - OpenVPN
  - …



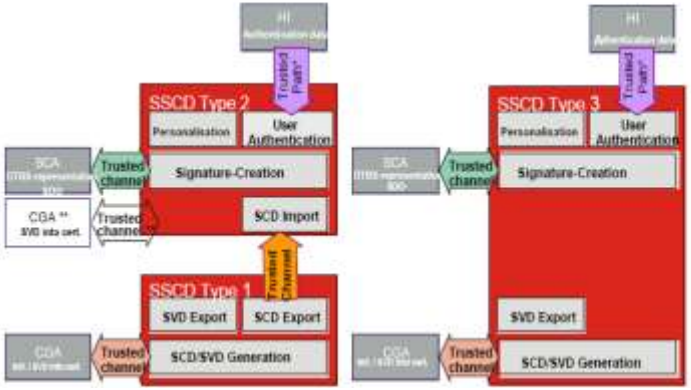
HSM – Prevent API Misuse: an example

- High Secure HSM: IBM4758
  - Hardware: FIPS 140-2 Level 4 Certified
  - Operating System: FIPS 140-2 Level 3 Certified
- API
  - Common Cryptographic Architecture (CCA)
  - NOT validated during FIPS certification
- University of Cambridge: « Extracting a 3DES key from an IBM4758 »
  - Physical access to the HSM
  - Misuse sequence of API together with brute-force
- Simular problems with standard APIs

HSM – Standards / Certifications (1)

- ISO-13491-1:2007 Banking – Secure Cryptographic Devices
  - Specifies Requirements for Secure Cryptographic Devices
  - Based on cryptographic processes defined in
    - ISO-9564: Banking – Personal Identification Number
    - ISO-16609: Banking – Requirements for Message Authentication
    - ISO-11568: Banking – Key Management

- Protection Profile – Secure Signature Creation Device
  - BSI-PP-0004-2002T 03.04.2002 – Type1
  - BSI-PP-0005-2002T 03.04.2002 – Type2
  - BSI-PP-0006-2002T 03.04.2002 – Type3



HSM – Standards / Certifications (2)

- Certifications:
  - FIPS 140-2; FIPS 140-3 (draft)
  - Common Criteria (CC)
  - PCI HSM (draft) from PCI SSC (Payment Card Industry Security Standards Council)
  - Local certifications: MEPS, ZKA, …

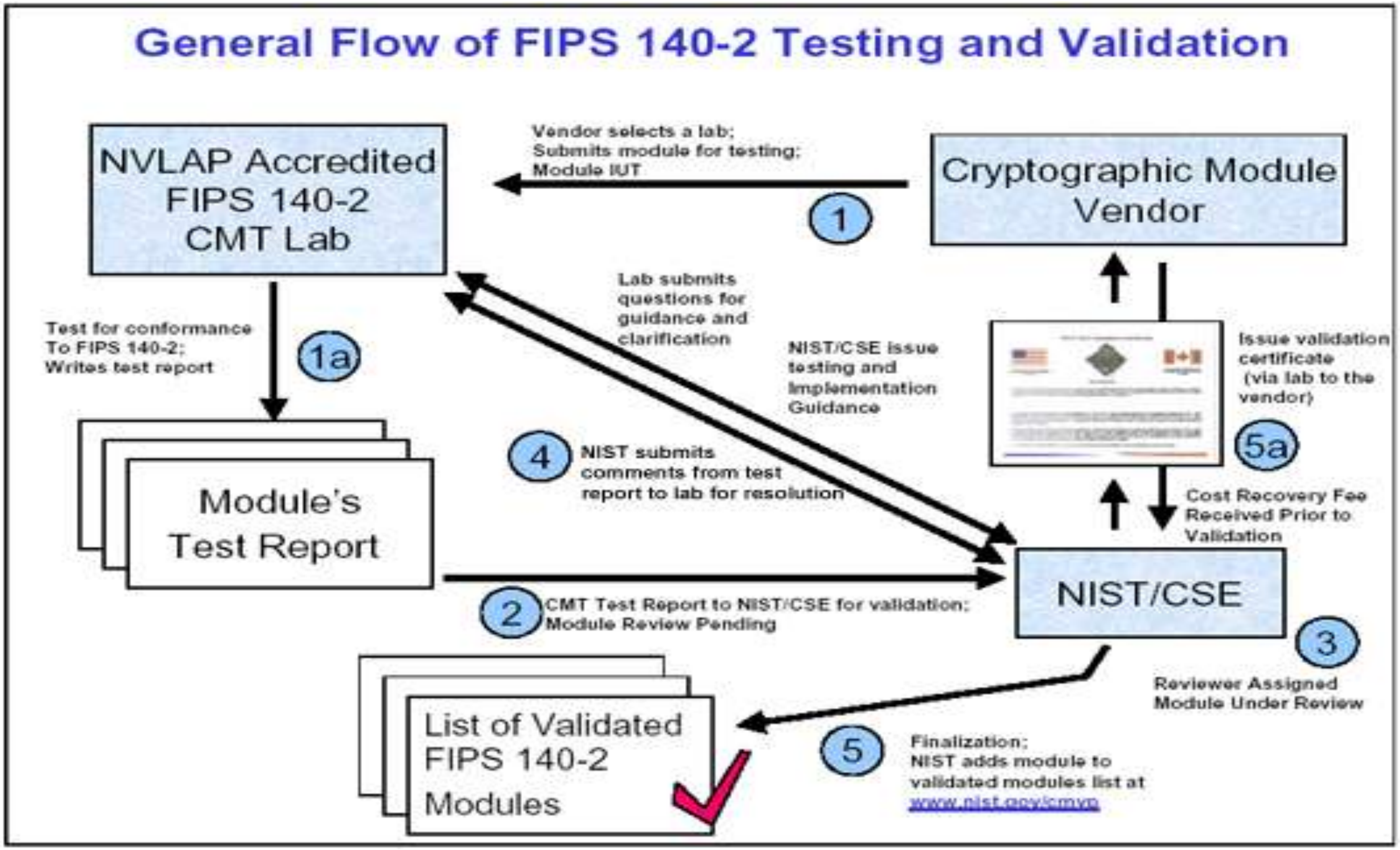
HSM – FIPS 140-2 (1)

- FIPS
  - Federal Information Processing Standard
  - US government computer security standard
  - Used to accredit cryptographic modules
  - Issued by NIST (National Institute of Standards and Technology)
  - Cryptographic Module Validation Program (CMVP)
- Security levels
  - Level 1: no specific physical security mechanisms
  - Level 2: tamper evidence requirement
  - Level 3: high probability of detecting and responding to attempts of physical access
  - Level 4: complete envelop of protection with the indent of detecting and responding to all unauthorized attempts of physical access

HSM – FIPS 140-2 (2)

- Requirement areas (11) for cryptographic modules
  - Specifications: what has to be documented
  - Parts/interfaces: which in/out information flows and how it must be segregated
  - Roles, services and authentication: who can do what and how it is checked
  - Final state model: documentation of high level states and transitions
  - Physical security: tamper evidence/responsiveness/resistance
  - Operational environment: which operating system
  - Cryptographic key management: generation, entry, output, storage and destruction of keys
  - EMI/EMC (Electromagnetic Interference/Compatibility)
  - Self-tests: what must be tested and when; what when a test fails
  - Design assurance: information to be provided
  - Mitigation of other attacks: how it is done

HSM – FIPS 140-2 Certification Process



General Flow of FIPS 140-2 Testing and Validation

NVLAP Accredited FIPS 140-2 CMT Lab
Cryptographic Module Vendor
Module's Test Report
NIST/CSE
List of Validated FIPS 140-2 Modules

1 Vendor selects a lab; Submits module for testing; Module IUT

1a Test for conformance To FIPS 140-2; Writes test report

2 CMT Test Report to NIST/CSE for validation; Module Review Pending

3 Reviewer Assigned Module Under Review

4 NIST submits comments from test report to lab for resolution

Lab submits questions for guidance and clarification

NIST/CSE issue testing and Implementation Guidance

5 Finalization; NIST adds module to validated modules list at www.nist.gov/cmvp

5a Issue validation certificate (via lab to the vendor)

Cost Recovery Fee Received Prior to Validation

HSM – Common Criteria (1)

- CC
  - Common Criteria for Information Technology Security Evalution (evaluation methodology)
  - No security levels (FIPS), but Evaluation Assurance Levels (EAL1-EAL7)
  - National certification bodies with Common Criteria Recognition Agreement (CCRA)
  - Definition of security in Security Target (ST)

HSM – Common Criteria (2)

- 7 Classes
  - ACM – Configuration Management
  - ADO – Delivery and Operation
  - ADV – Development
  - ADG – Guidance documentation
  - ACL – Lifecycle support
  - ATE – Tests
  - AVA – Vulnerability Analysis

HSM – PCI HSM

- PCI SSC = VISA, MASTERCARD, JCB, AMEX, DISCOVERY
- Range of end-to-end security requirements: PCI PED, PCI UPT, PCI DSS, PCA PA DSS, PCI PIN and… PCI HSM
- Still draft
- Based upon FIPS, including payment functionality
- Own certification scheme

HSM – Manufacturers (1)

- Atos Worldline SA/NV

- Safenet

- Bull

- IBM

HSM – Manufacturers (2)

- Ncipher (now Thales)

- Utimaco

- Thales

- ARX

Q&A

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