The Untapped Potential of TEEs on Mobile Devices

Jan-Erik Ekberg, Kari Kostiainen, N. Asokan

Financial Crypto 2013

What is a TEE?

Processor, Memory, Storage, Peripherals

Trusted Execution Environment

Isolated & Integrity-protected

from the “normal” execution environment (aka Rich Execution Environment)

Chances are that:
You have devices with hardware-based TEEs in them!
But you don’t have (m)any apps using them.

Outline

A brief look back: How did this come to pass?

Hardware security features on mobile devices

On-board Credentials: opening up TEEs for app developers

A look ahead: standardization and beyond

A Look Back

Why do most mobile devices today have TEEs?

Platform security for mobile phones

Mobile network operators;

1. Subsidy locks → immutable ID
2. Copy protection → device authentication, app. separation
3. …

Regulators;

1. RF type approval → secure storage
2. Theft deterrence → immutable ID
3. …

End users;

1. Reliability → app. separation
2. Theft deterrence → immutable ID
3. Privacy → app. separation
4. ...

Closed → Open
Different Expectations compared to the PC world

Early adoption of platform security

Both IMSI and IMEI require physical protection.

GSM 02.09, 1993

Physical protection means that manufacturers shall take necessary and sufficient measures to ensure the programming and mechanical security of the IMEI. The manufacturer shall als
(where applicable) rem

The IMSI is stored securely within the SIM.

3GPP TS 42.009, 2001

The IMEI shall not be changed after the ME's final production process. It shall resist tampering, i.e. manipulation and change, by any means (e.g. physical, electrical and software).

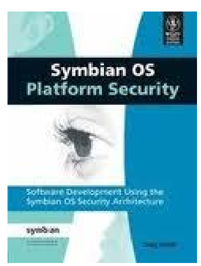
NOTE: This requirement is valid for new GSM Phase 2 and Release 96, 97, 98 and 99 MEs type approved after 1st June 2002.

Different starting points:
widespread use of hardware and software platform security

~2001 **~2002** **~2005** **~2008**

J2ME

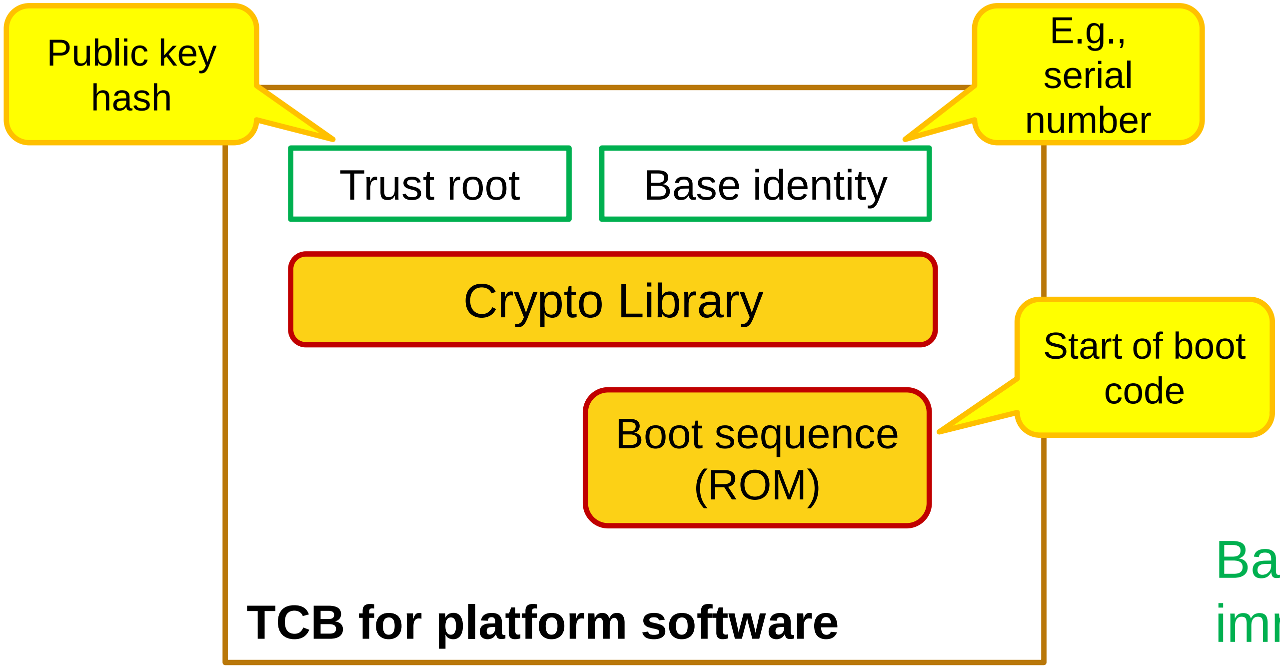
TrustZone®
Security Foundation by ARM®



Hardware Security Features

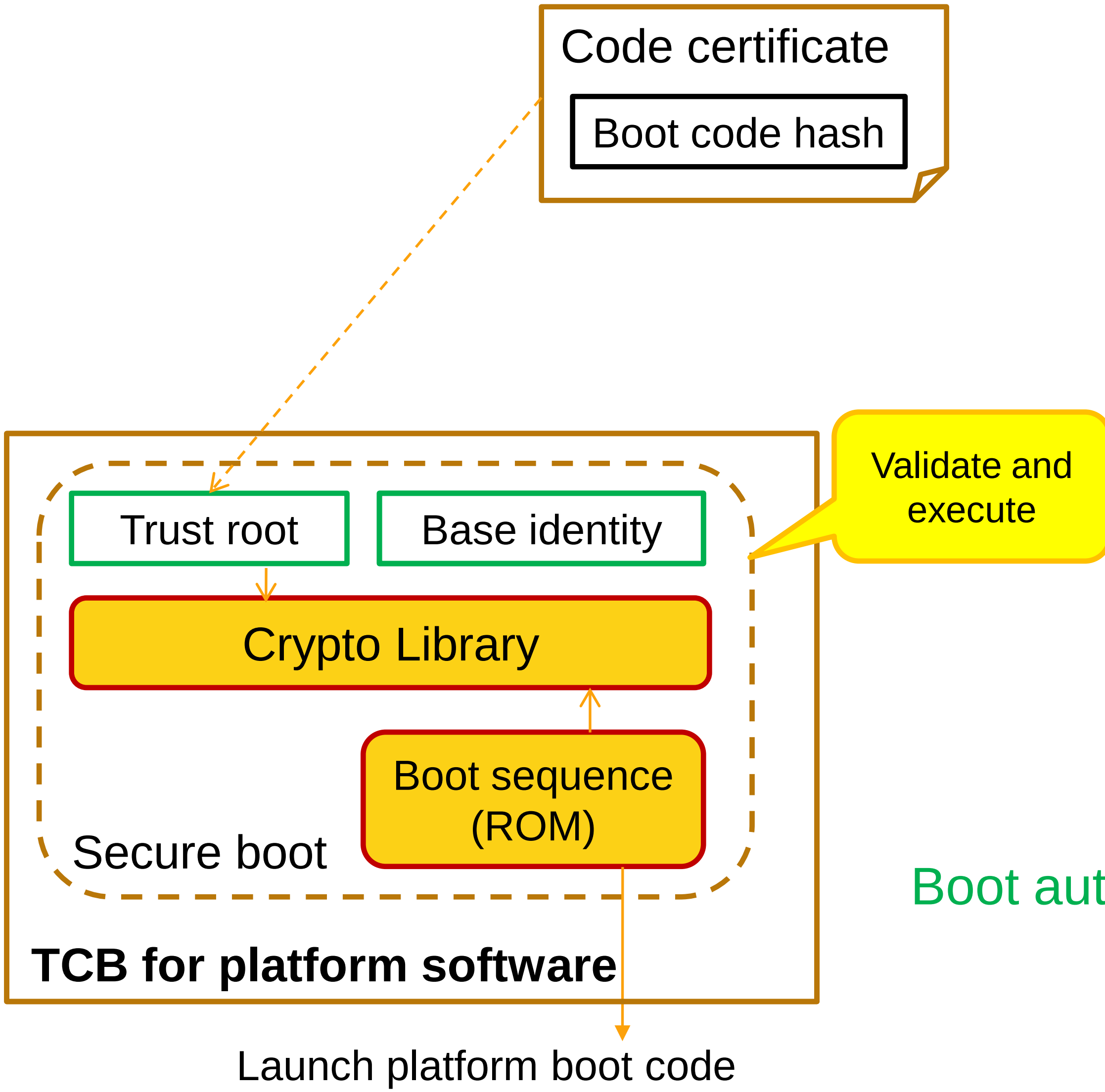
What is in a TEE?

Hardware support for platform security



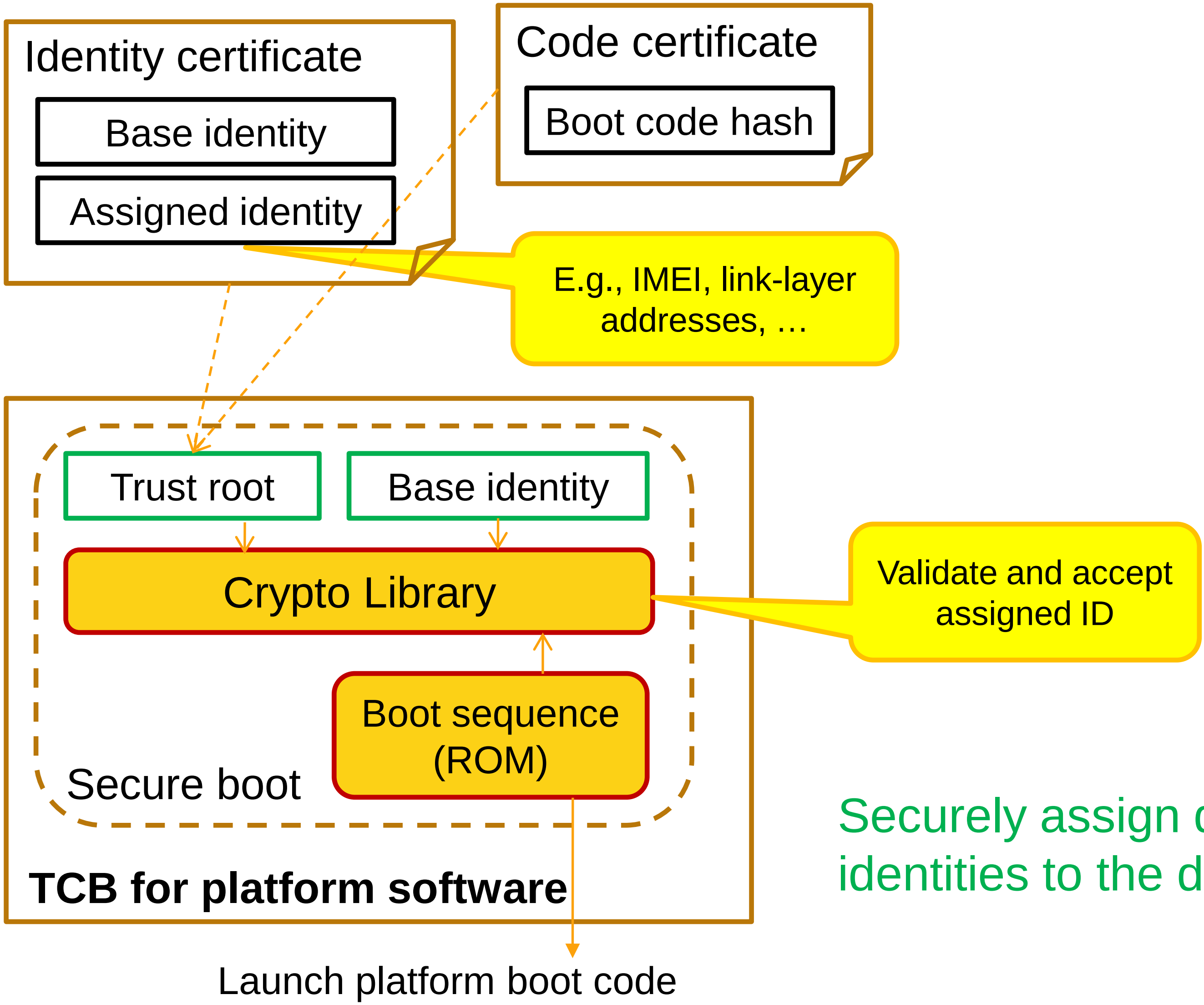
Basic elements in immutable storage

Secure bootstrapping



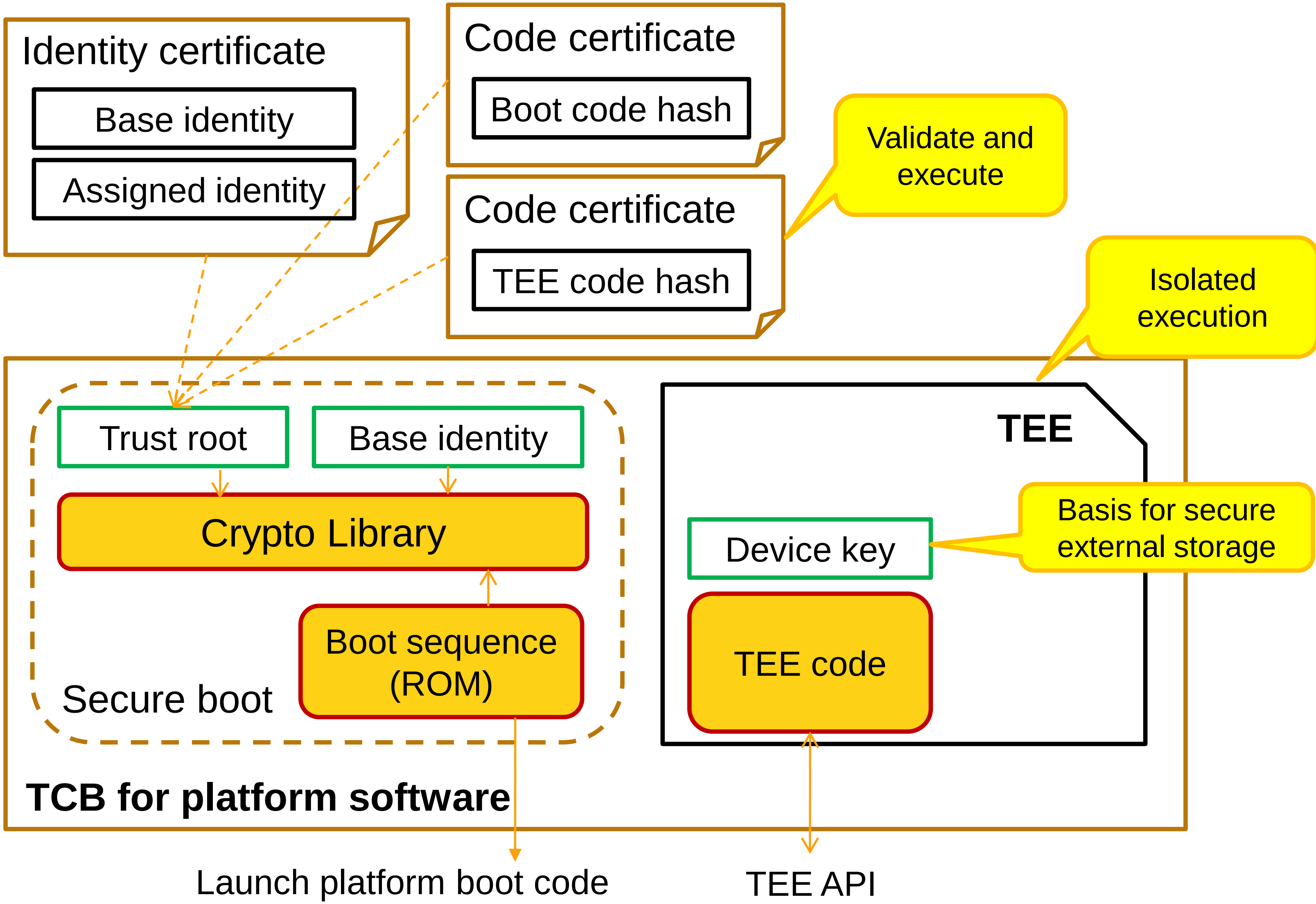
Boot authorized code only

Identity binding



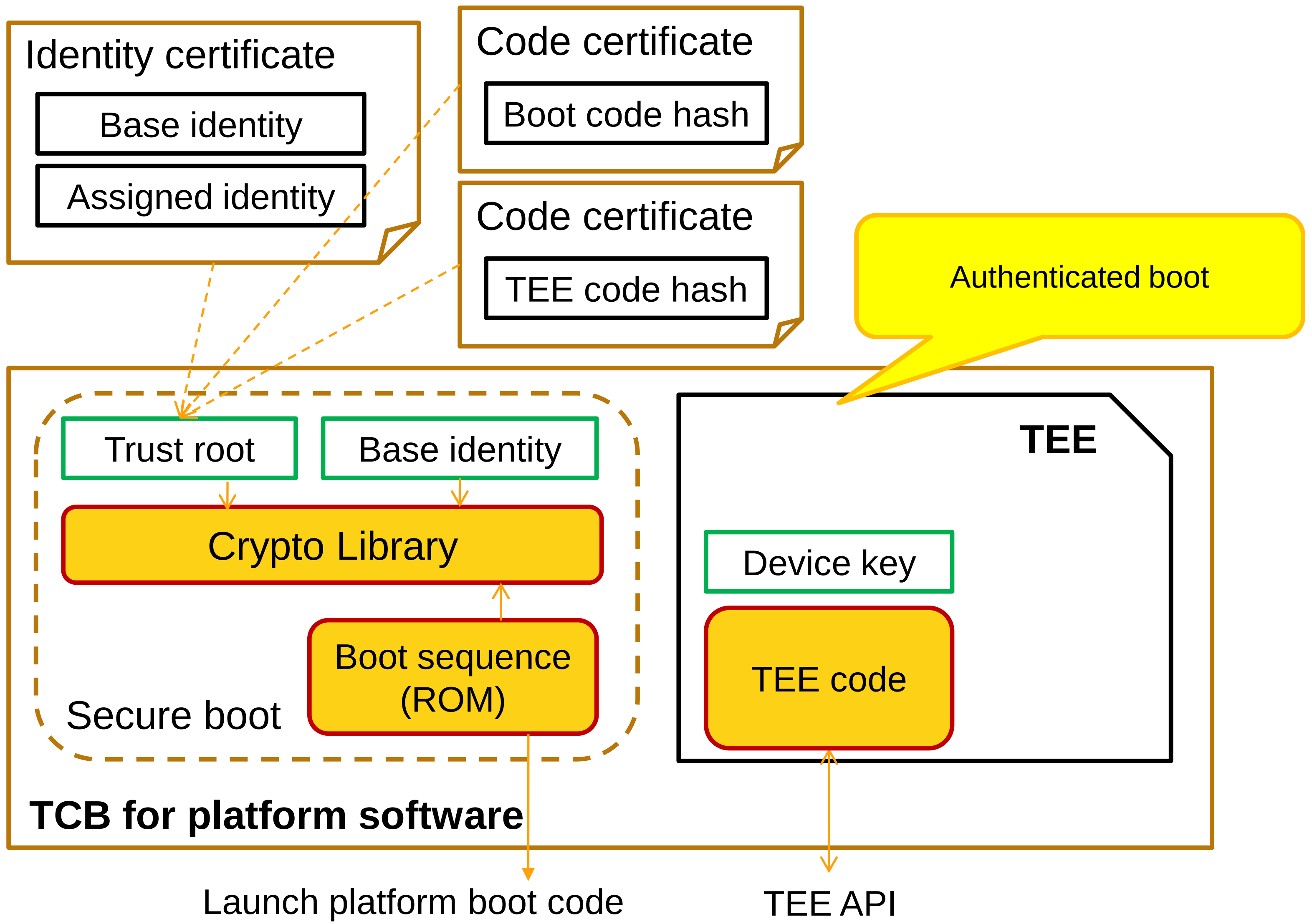
Securely assign different identities to the device

Trusted execution environment (TEE)

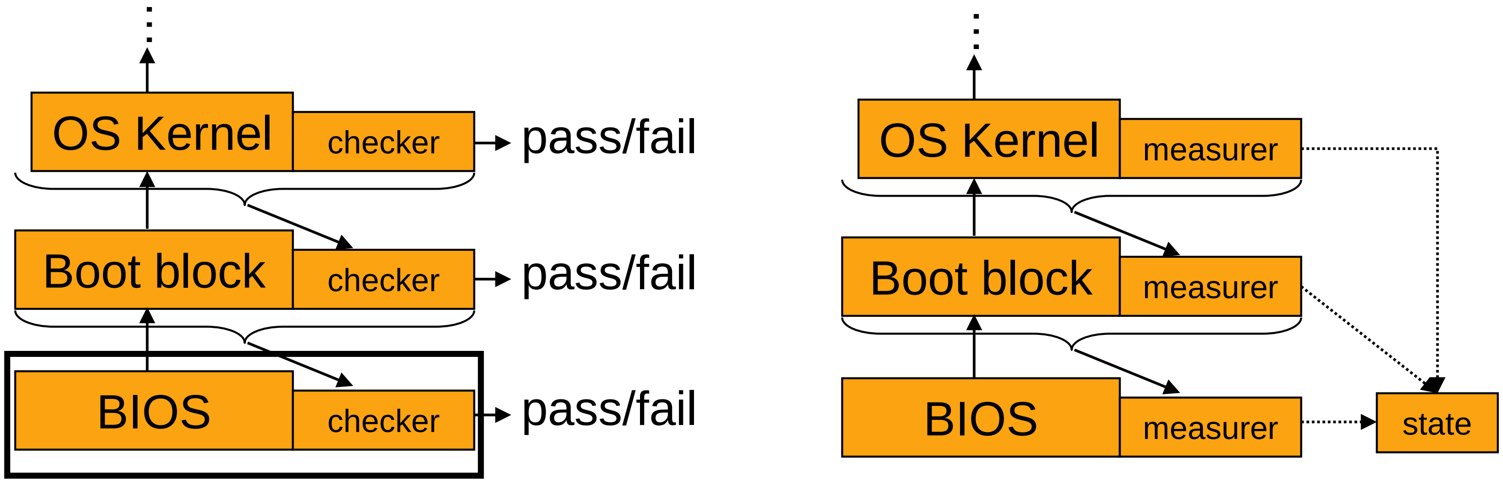


Authorized execution of arbitrary code, isolated from the OS; access to device key

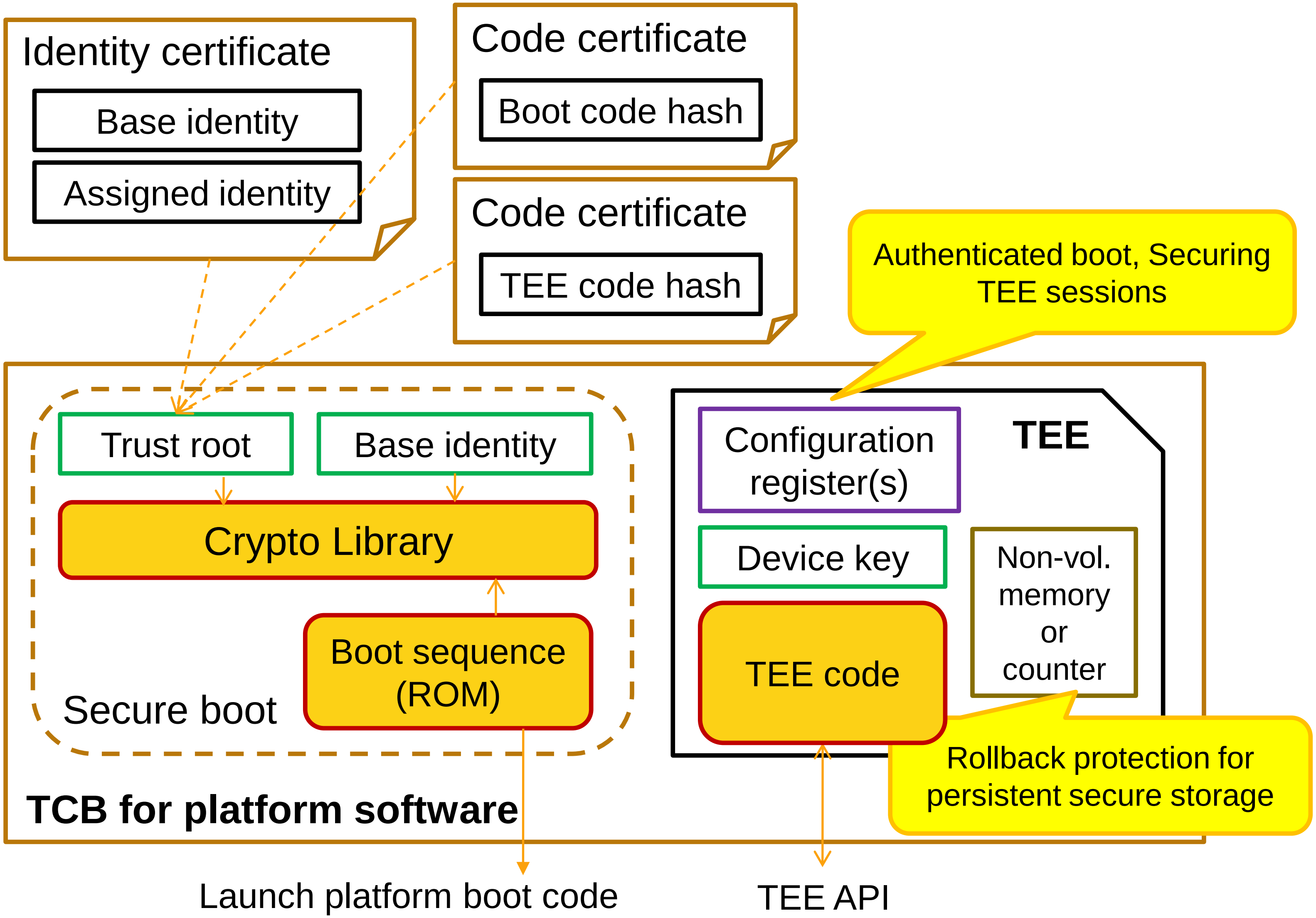
Secure state



Secure boot vs Authenticated boot

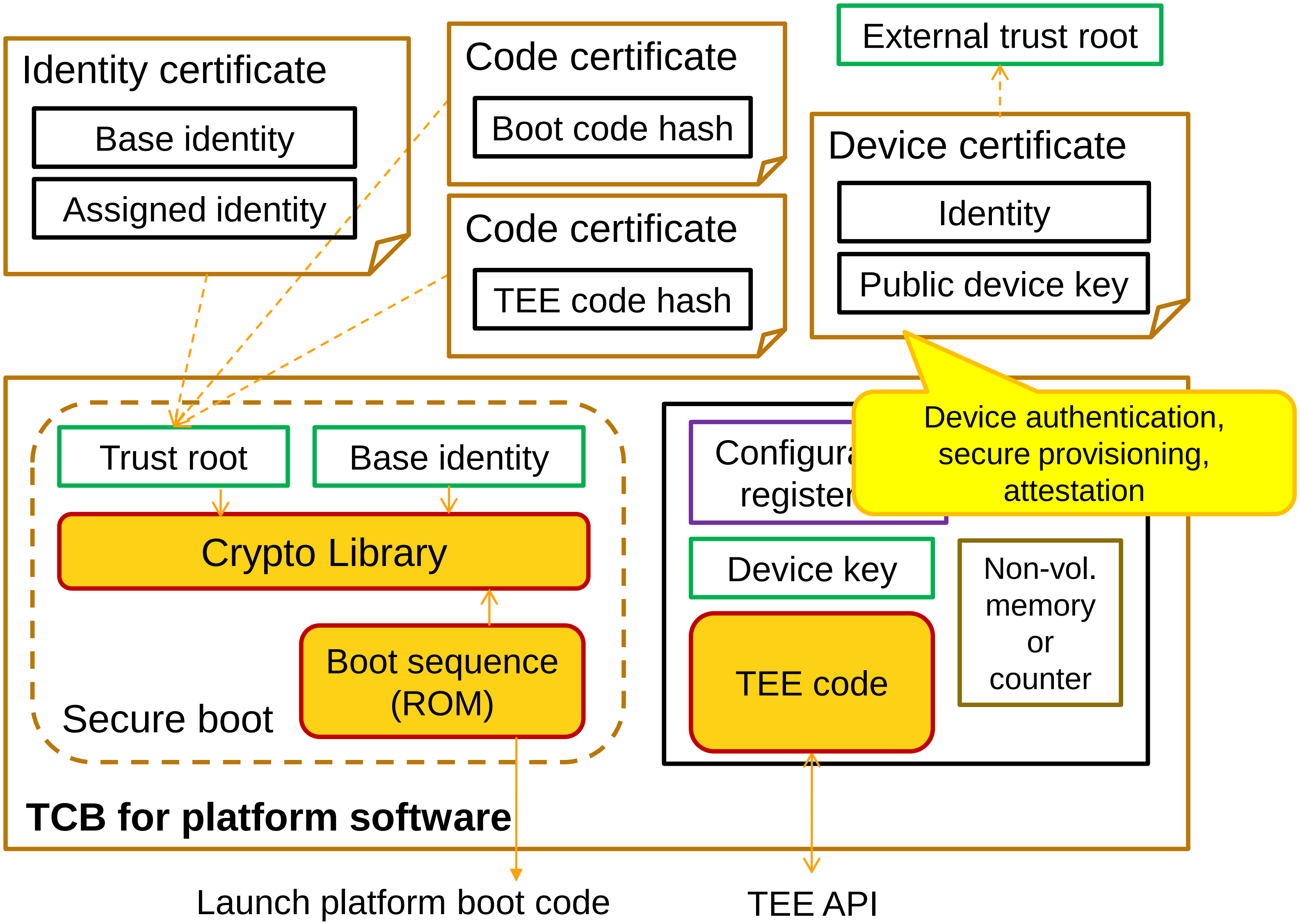


Secure state



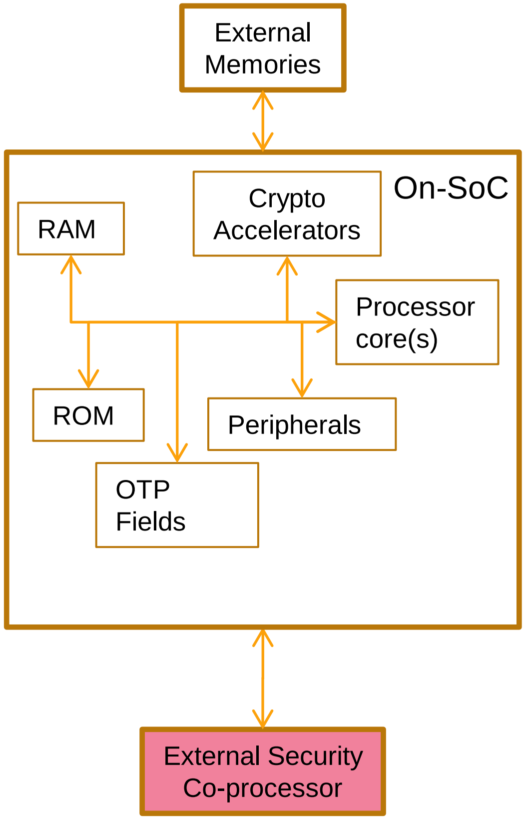
Integrity-protected state within the TEE

Device authentication

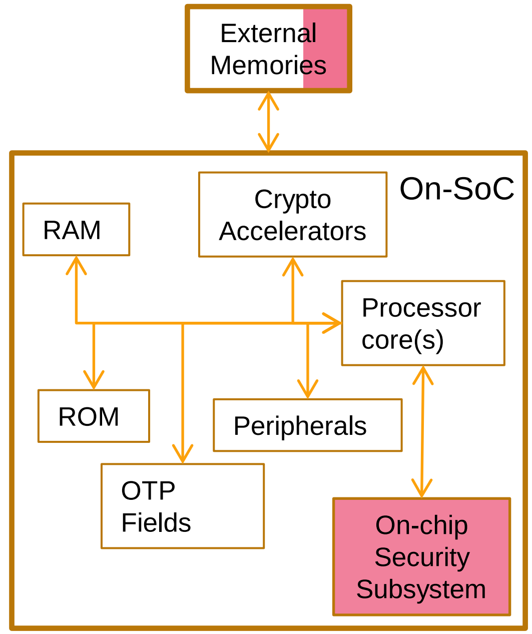


Prove device identity or properties to external verifier

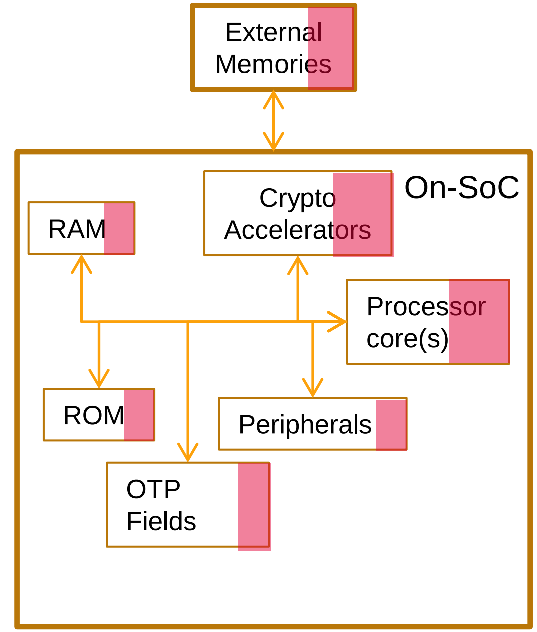
Architectural options for realizing TEEs



External Secure Element



Embedded Secure Element



Processor Secure Environment

TEE component

Figures taken from "GlobalPlatform Device Technology, TEE System Architecture", Version 1.0, December 2011

Hardware security architectures (mobile)

Processor Secure Environment

TI M-Shield, ARM TrustZone

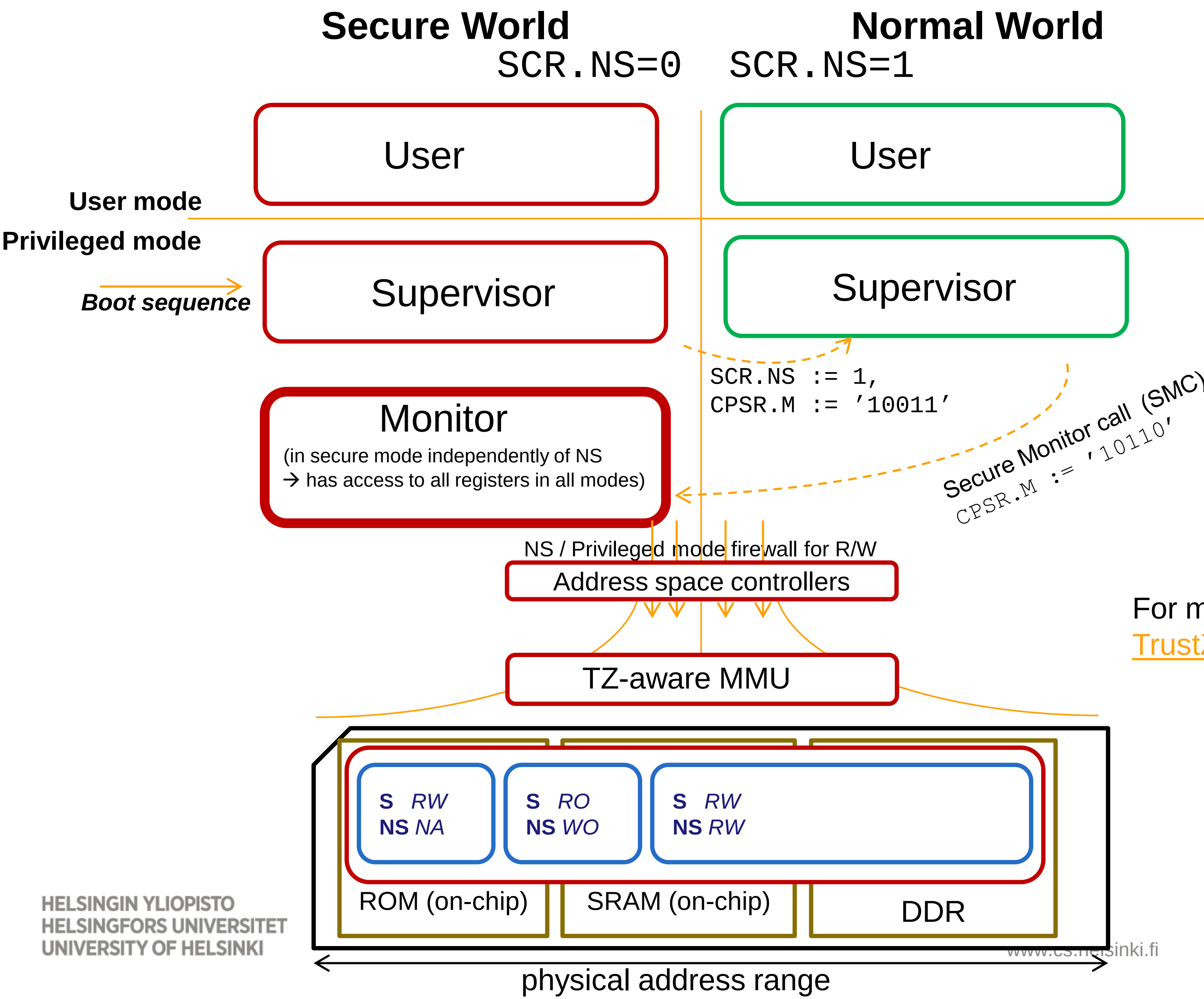
Augments central processing unit: “Secure processor mode”

Isolated execution with on-chip RAM: limited (e.g., < 20kB)

Access to memory locations can be restricted based on mode

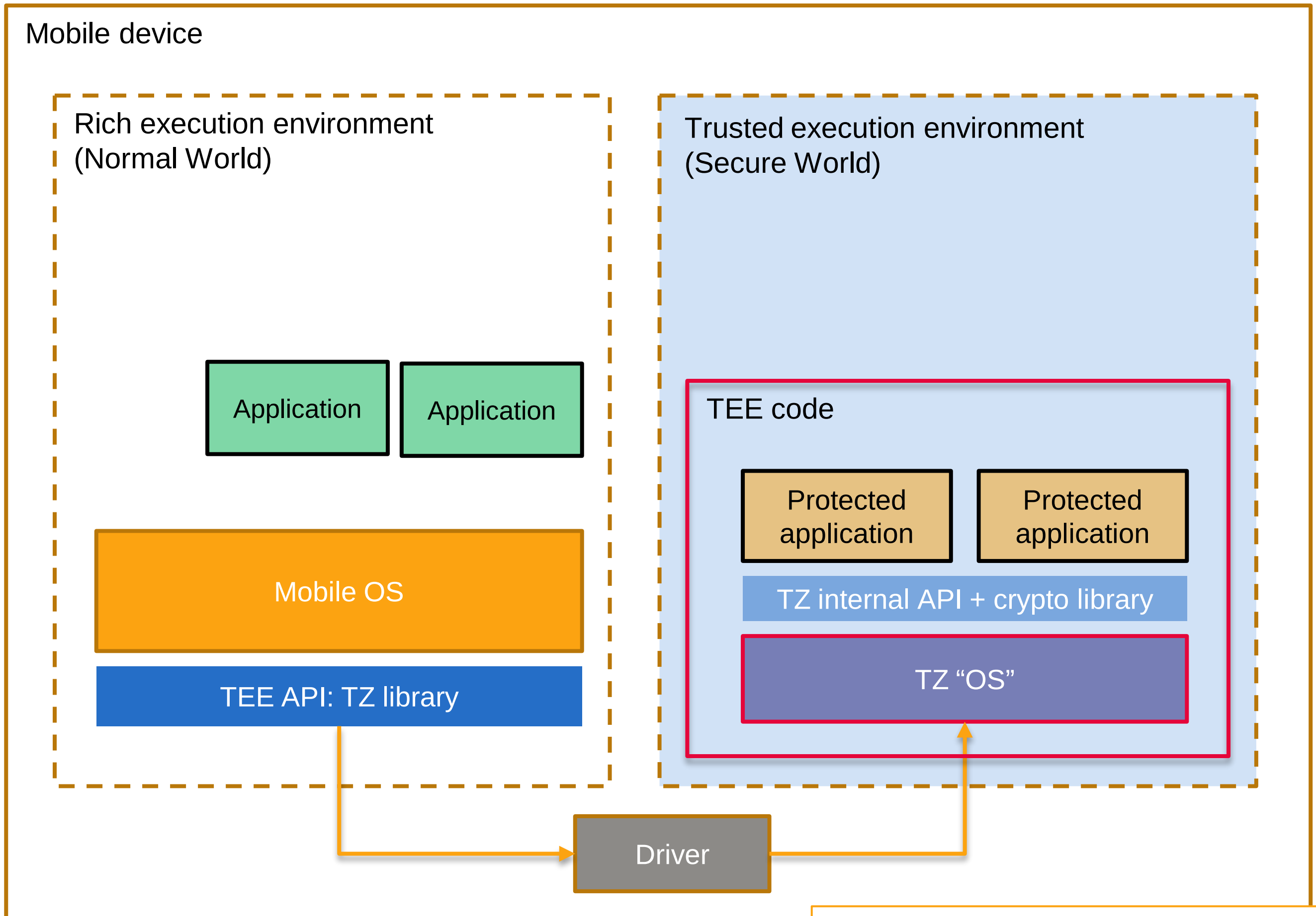
Secure storage: e.g., using write-once restricted-read e-fuses

Processor modes in TrustZone



For more information, [TrustZone pages at ARM]

Using a TEE: the TrustZone example



All Protected Applicationss are equal
No open developer API on REE side

Hardware security architectures (TCG)

Trusted Platform Module (TPM)

External Secure Element

- Standalone processor on PCs
- Isolated execution for pre-defined algorithms
- Arbitrary isolated execution with DRTM (“late launch”)
- Platform Configuration Registers (PCRs)
- Monotonic counters

TPM Mobile(previously known as MTM)

Multiple implementation options

- Mobile variant of TPM
- Defines interface
- Implementation options: TrustZone, M-Shield, software

Hardware platform security features: summary

Secure boot: Ensure only authorized boot image can be loaded

Authenticated boot: Measure and remember what boot image was loaded

Identity binding: Securely assign different identities to the device

Secure storage: protect confidentiality/integrity of persistent data

Isolated execution: Run authorized code isolated from the device OS

Device authentication: Prove device identity to external verifier

Remote attestation: Prove device configuration/properties to external verifier

Uses of hardware security

For device manufacturer and operator:

Immutable ID

- secure boot, identity binding

Copy protection

- secure boot, identity binding, device authentication, secure storage, isolated execution

Subsidy lock

- secure boot, identity binding, secure storage, isolated execution

...

How can developers make use of hardware security?

On-board Credentials

Opening up TEEs for App developers

On-board Credentials (ObCs)

An open credential platform that leverages on-board trusted execution environments

Secure yet inexpensive

On-board Credentials (ObCs)

SW-only credentials

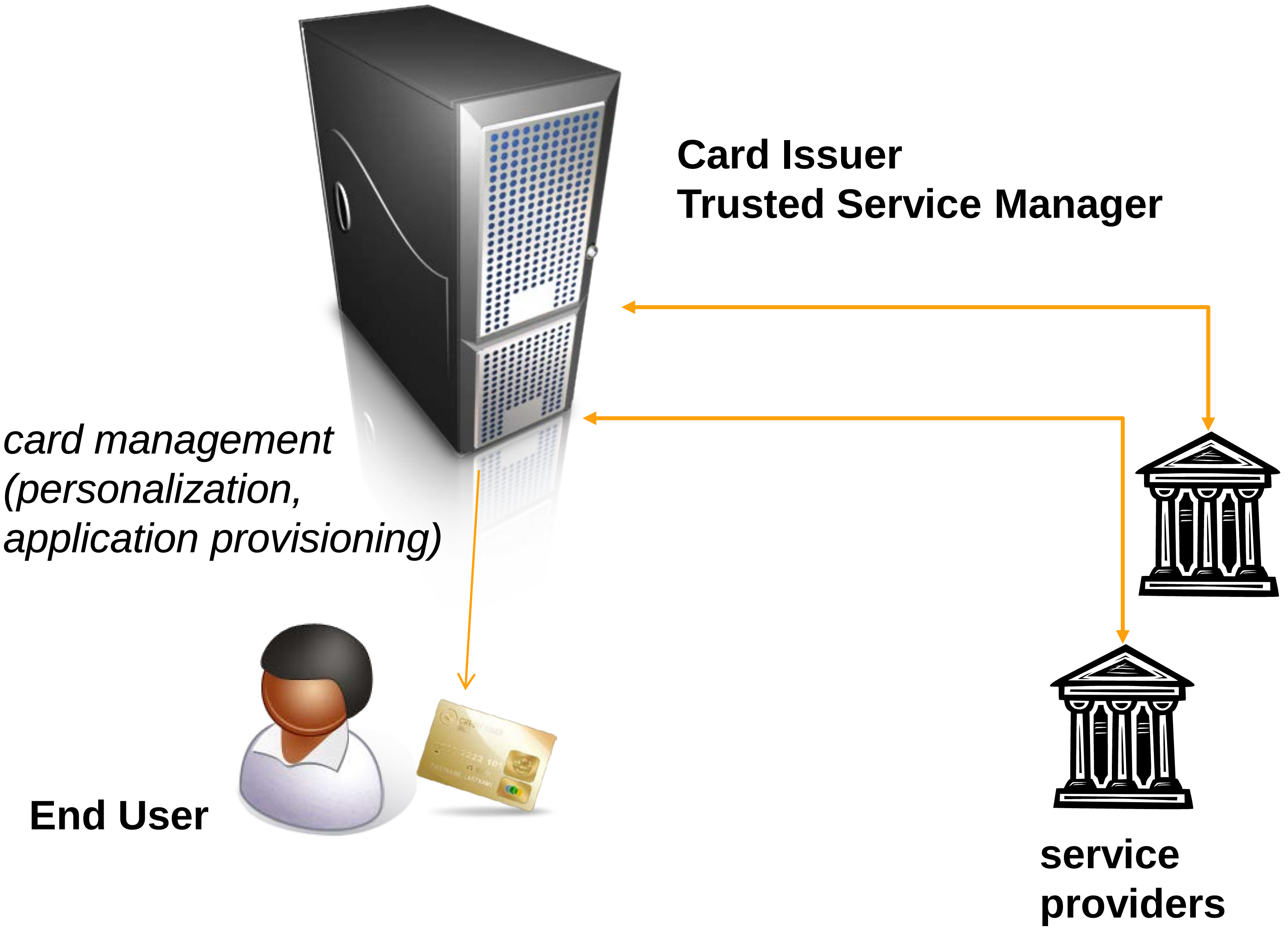
- Easy, cheap, flexible
- Insecure

Dedicated HW credentials

- Secure, intuitive
- Expensive, inflexible, single-purpose

Open (provisioning): Like multi-application smartcards, but without issuer control.

Issuer-centric provisioning for smartcards



On-board user credentials: design goals

Credential programs can be executed securely

Credential = program + secret

Credential secrets can be stored securely

Anyone can create and use new credential types

- Security model to strongly isolate credential programs from one another
- Avoid need for centralized certification of credential programs

Anyone can provision credential secrets securely to a credential program

- Need a mechanism to create a secure channel to the credential program
- (certified) device keypair; unique identification for credential programs

Protection of asymmetric credentials is attestable to anyone

- Anyone can verify that a private key is protected by the TEE

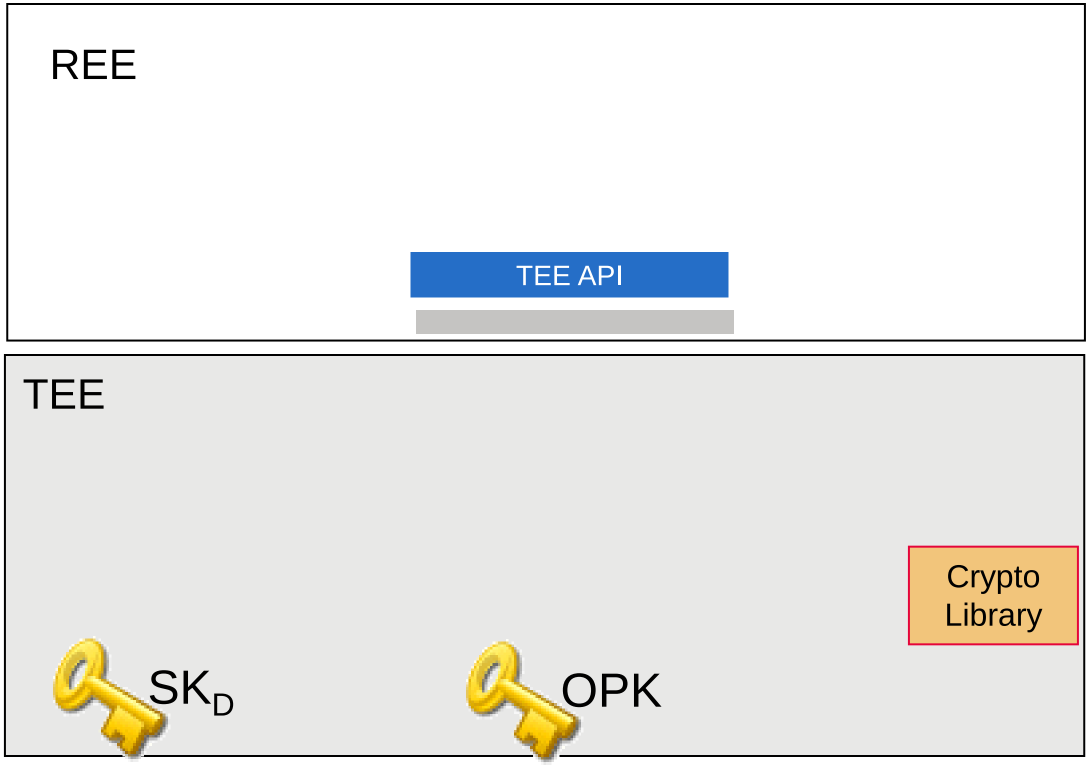
Design constraints

- No fine-grained access control within TEE
- Small on-chip memory (too small for standard interpreters)
- Open provisioning implies no fixed trust domains/hierarchies

ObC Architecture

Build on any TEE that supports:

- Secure execution (within TEE)
- Secure storage (secret key OPK in TEE)
- Certified device keypair (PK_D/SK_D in TEE), $CERT_D$
- Source of randomness



ObC Architecture

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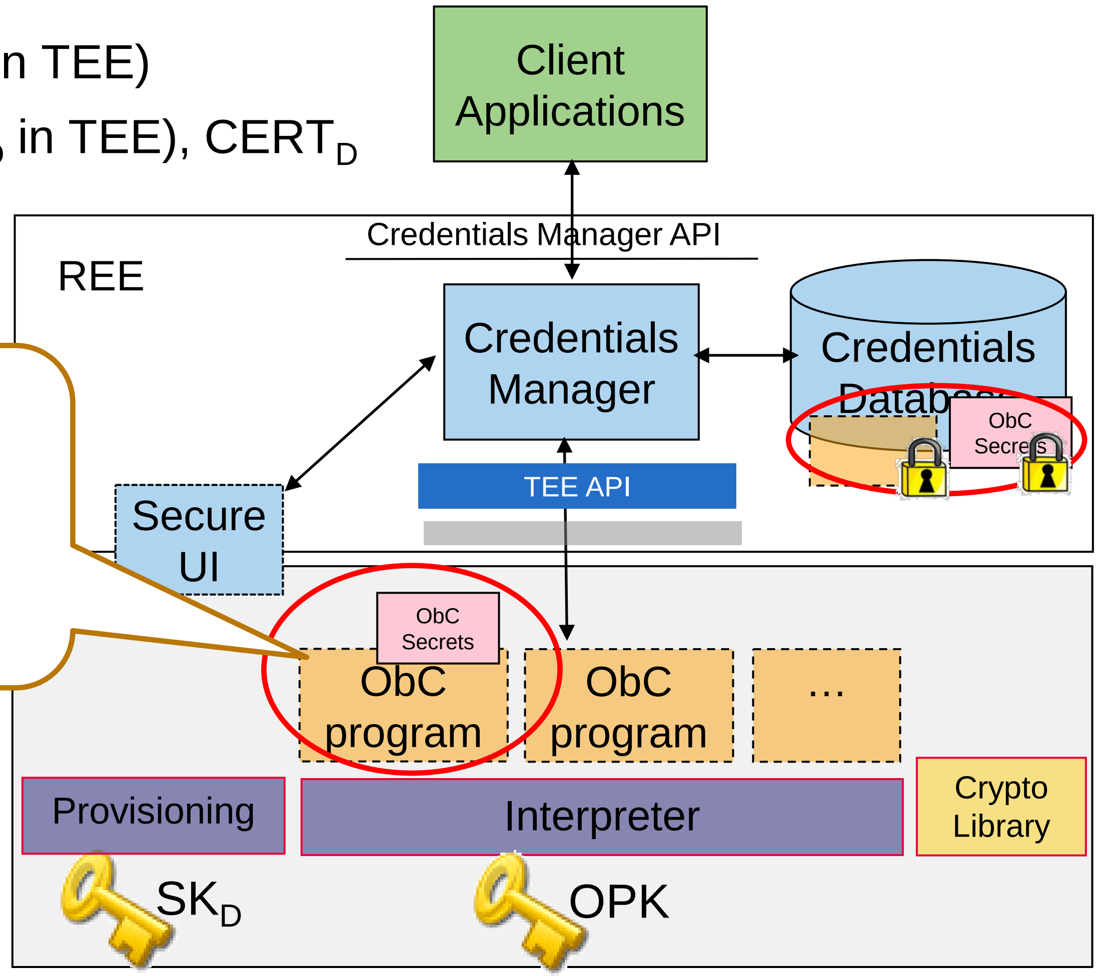



```
function main()
  read_array(IO_PLAIN_RW, 0, data)
  read_array(IO_SEALED_RW, 1, key)
  aesenc(cipher, data, key)
  write_array(IO_PLAIN_RW, 0, cipher)
  return 0
end
```

"On-board Credentials with Open Provisioning", Kostiainen et al, ASIACCS '09

Isolation of ObC Programs

Isolating the platform from ObC programs

- Constraining the program counter, duration of execution, …

Isolating ObC programs from one another

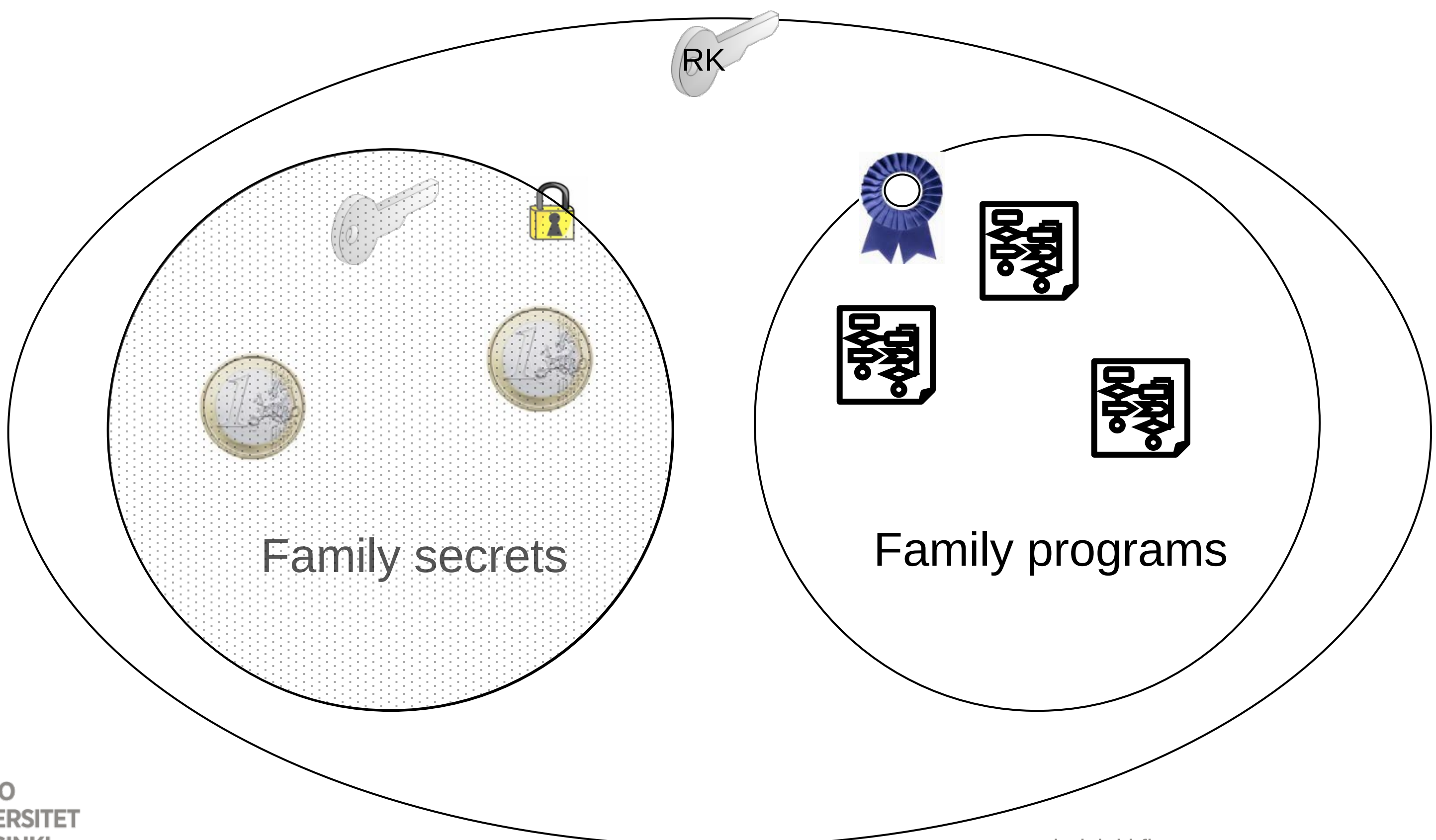
- Only one ObC program can execute at a time
- An ObC program can “seal” data for itself
  - Sealing key is different for every independent ObC program

    Sealing-key = KDF (OPK, program-hash)
  - A program can invoke functions like “seal(data)” (unsealing happens automatically on program loading)

Provisioning credential secrets (1/3)

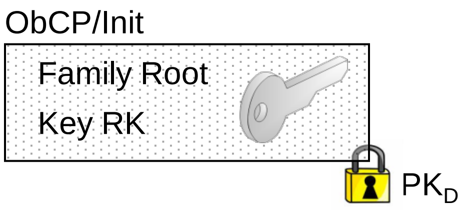
Idea: a **family** of credential secrets + credential programs endorsed to use them

“family” = dynamic trust domain; **same-origin** authorization policy

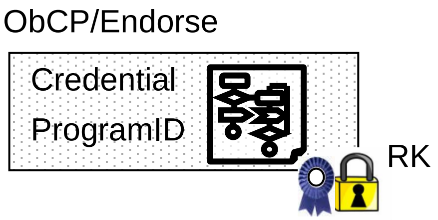


Provisioning credential secrets (2/3)

- Provision a family **root key** to the device
  - using ***authentic* device public key** PK_D



- Transfer encrypted credential secrets
  - using authenticated encryption (AES-EAX) with RK



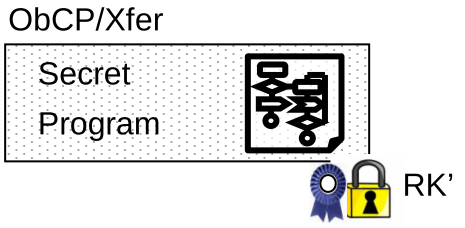
- Endorse credential programs for family membership
  - Program ID is a cryptographic hash of program text
  - using authenticated encryption (AES-EAX) with RK

Provisioning credential secrets (3/3)

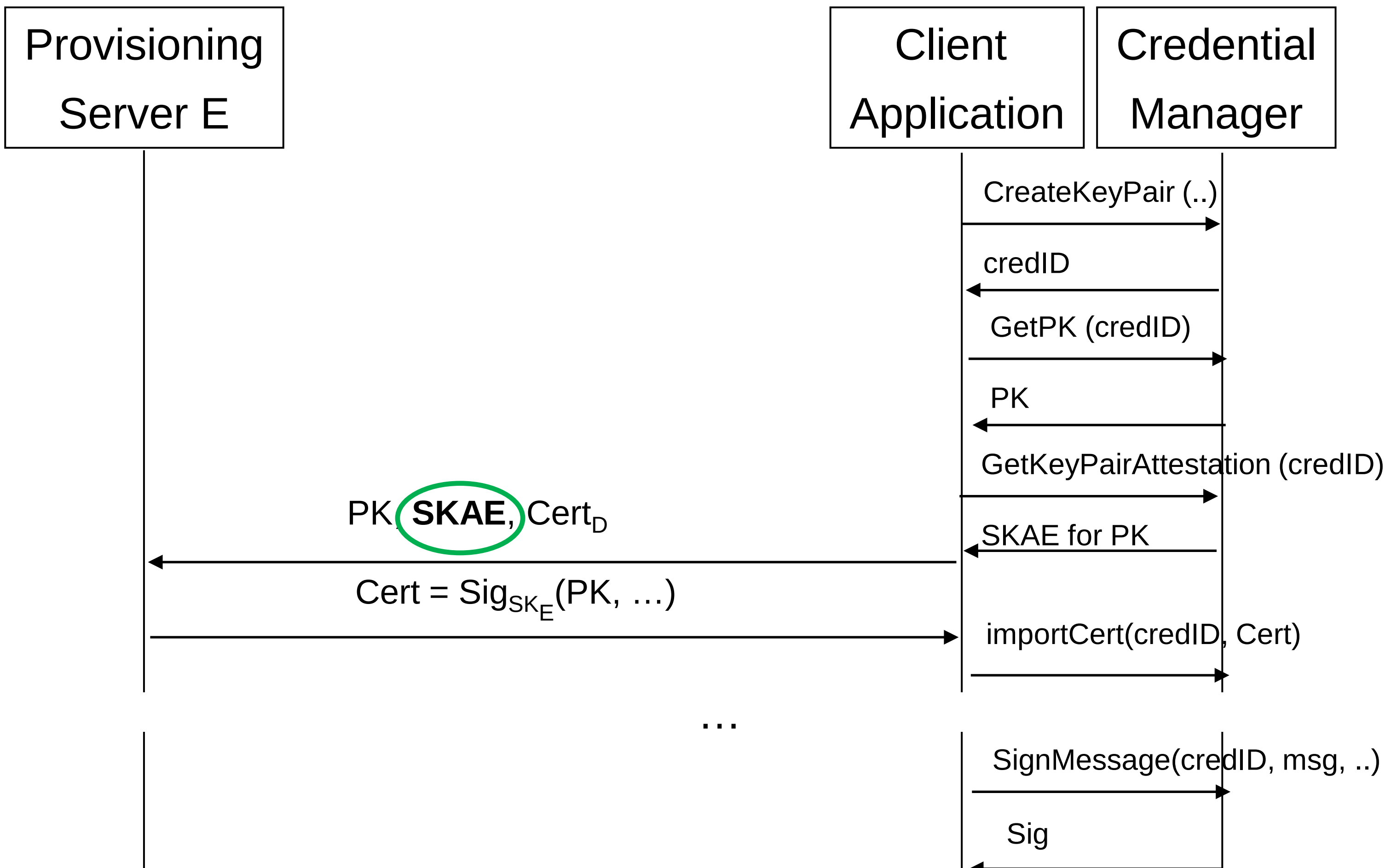
Anyone can define a family by provisioning a root key (“Same Origin” policy)

Multiple credential secrets and programs can be added to a family

Credential Programs can be encrypted as well



Asymmetric ObCs



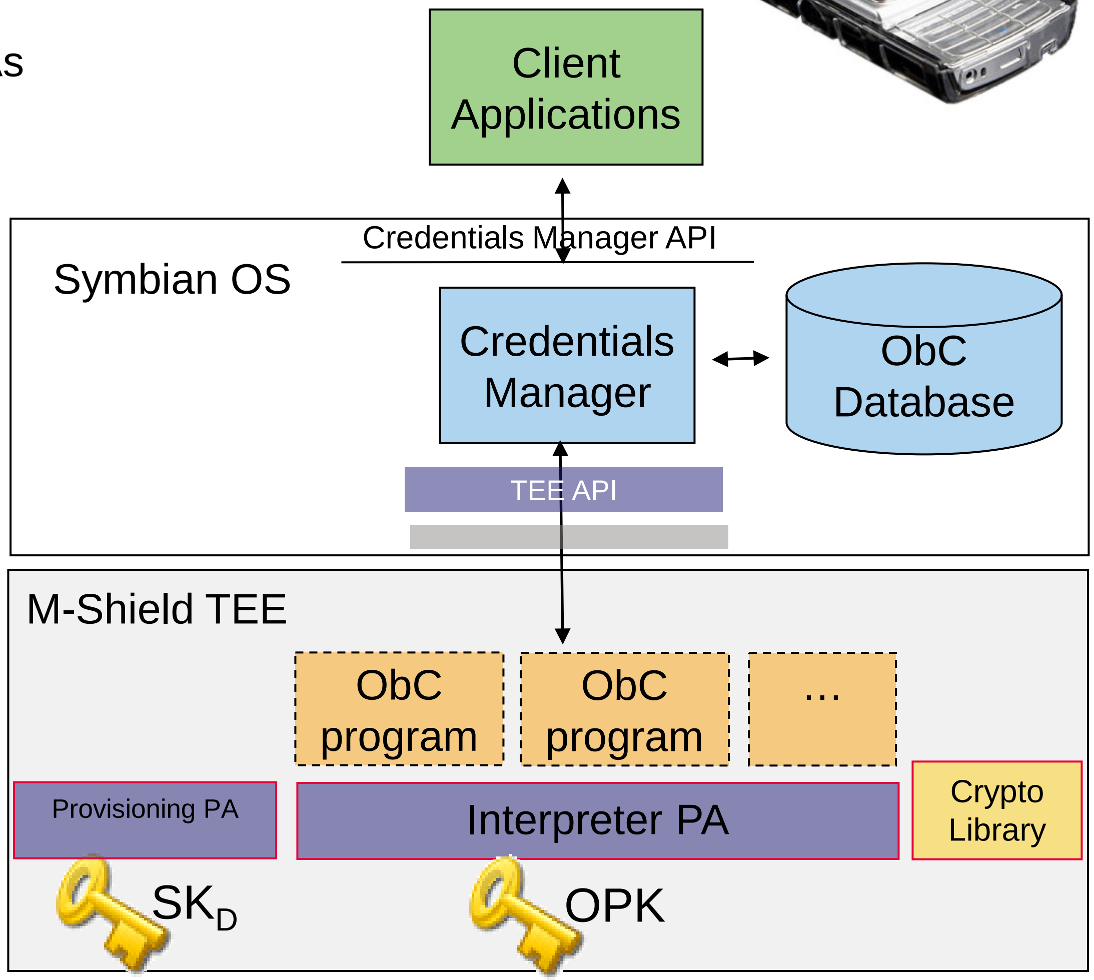
Cert$_D$ (Device certificate) Certificate for PK$_D$ issued by manufacturer

SKAE (Subject Key Attestation Evidence) for PK: Signature on PK by SK$_D$, attesting: SK **is within TEE** and **who can use SK**

"Key Attestation from Trusted Execution Environments", Kostiainen et al, TRUST 2010

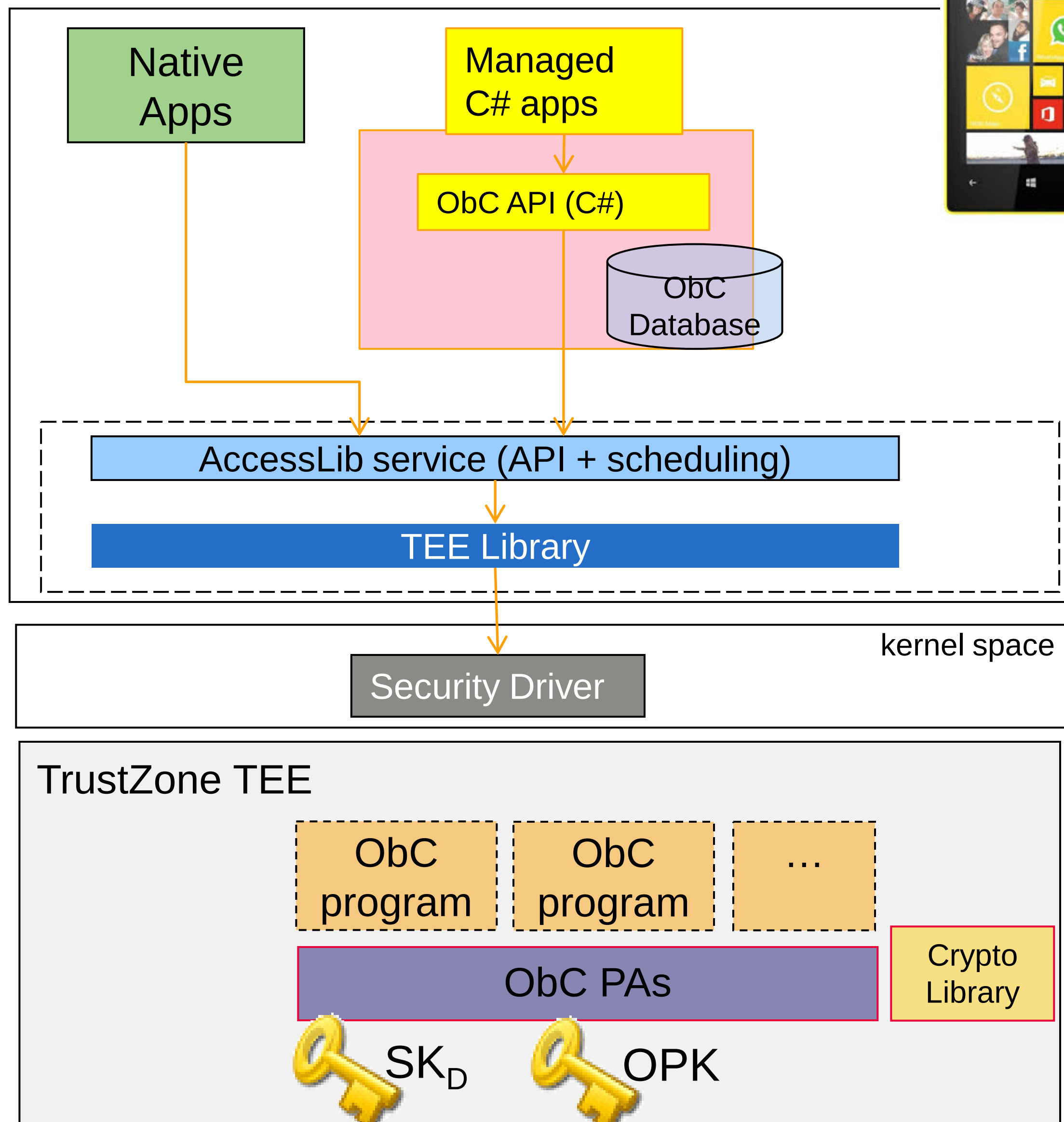
ObC on Symbian, M-Shield/TrustZone (2007-2009)

- M-Shield/TrustZone secure boot used for validation of OS
- Interpreter, provisioning system are PAs
  - Use on-chip RAM
- OPK from chip-specific secret
- Device key pair
  - generated by Prov. PA
  - protected by OPK
  - [certified by manufacturer]



ObC on Lumia WP8/TrustZone (2011-2013)

- TZ secure boot for OS validation
- OPK from chip-specific secret
- Device key pair
    - protected by OPK
    - certified during manufacture
- Previous instantiations for
    - different OSs: Symbian, MeeGo, Linux
    - different TEEs: M-Shield, TPM



[Skip to ObC examples]

ObC Features

Secure user credentials

Custom Credentials

Secure key/code provisioning

Built-in Credentials

Key attestation or Secure key Provisioning

Device Certification

Validate device platform

Platform authentication

Device Authentication

Application Authentication

Content attestation

Example usage scenarios: Platform Authentication

Prove to a third party (e.g., external server)

Device authentication: identity of device

- E.g., CAPTCHA-avoidance

Application authentication: identity of application/process

- E.g., Extended Web Service APIs for trusted apps

Content attestation: type of content

- E.g., Enforcing driver distraction rules in MirrorLink

MirrorLink Remote Attestation

Smartphone

Car head unit

User input

Content for user output

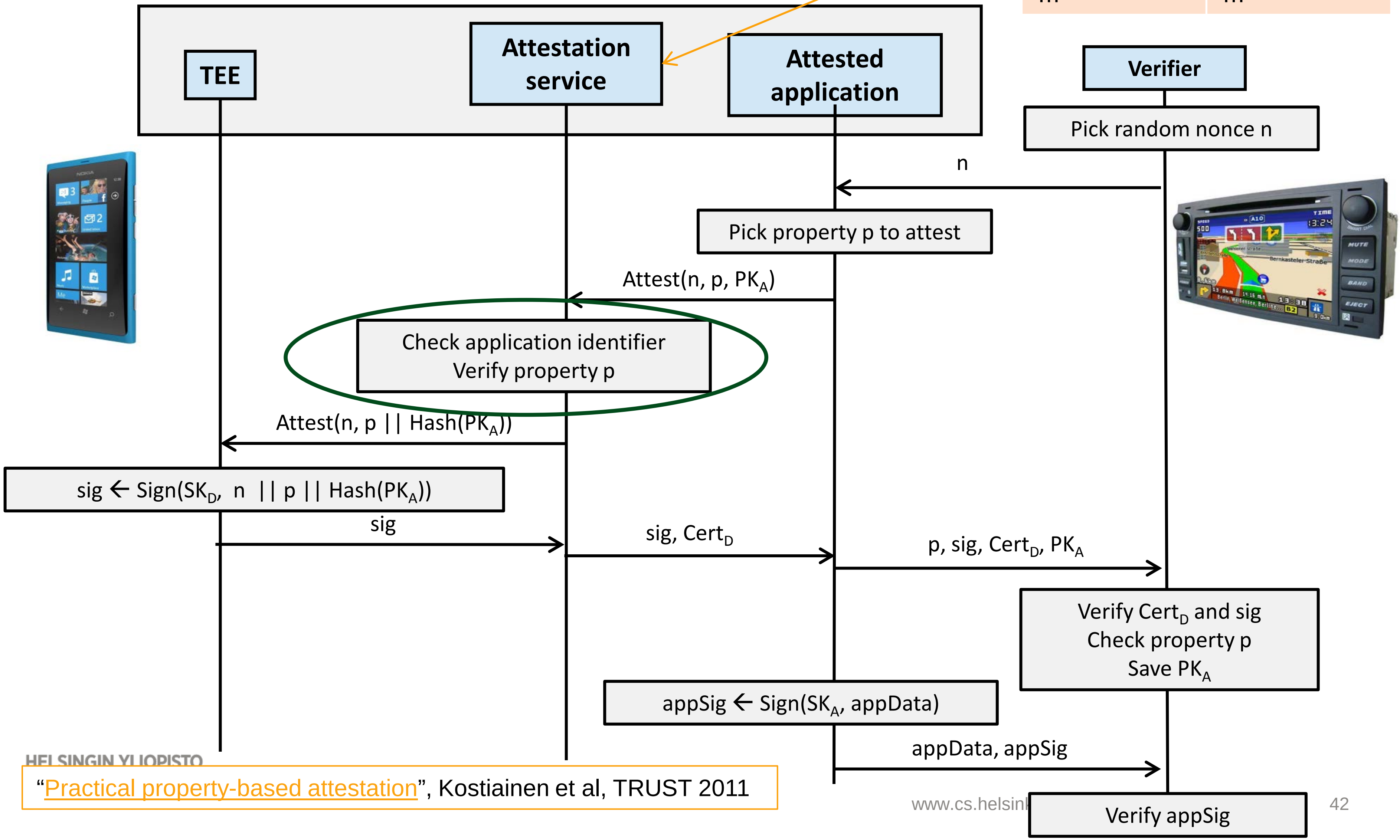
Enforcement of Driver distraction regulations

“Head unit can use attestation for enforcing driver distraction

http://mirrorlink.com/

Attestation protocol

Application Identifier	Property
App1	P1, P2
App2	P3
…	…



"Practical property-based attestation", Kostiainen et al, TRUST 2011

Example usage scenarios: User Credentials

Provision and store user credentials to user's personal device

User benefits:

- "no need to a bunch of different security tokens";
- "digital credentials provisioned easily" (http, e-mail, …)

Phone-as-smartcard: use device-resident credentials from legacy PC apps (e.g., browsers, Outlook, VPN clients)

NFC Transport ticketing

"Soft" tokens: embedded SIM, embedded SecurID

…

Phone as smartcard (PASC)

Applications use public key (PK) cryptography via standard frameworks

- Crypto API (windows), Cryptoki (Linux, Mac), Unified Key/cert store (Symbian)
- Agnostic to specific security tokens or how to communicate with them

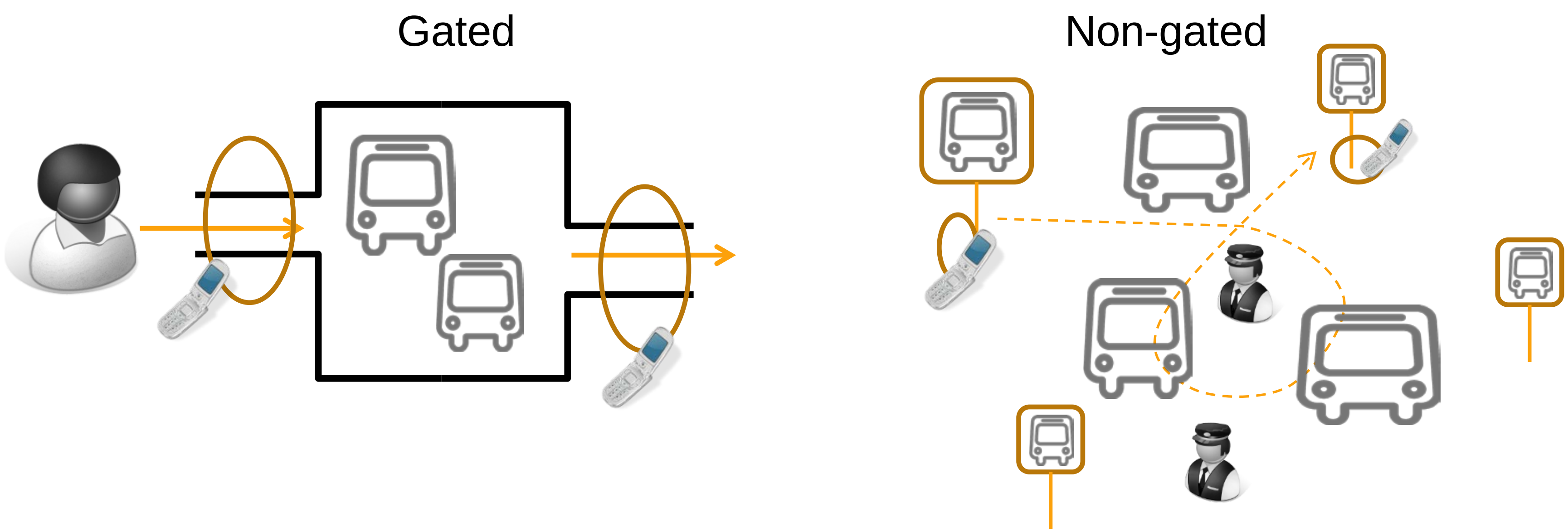
→Any PK-enabled smartcard can be used seamlessly with PK-aware applications!

What if mobile phone can present itself as a PK-enabled smart card?

"Can hand-held computers *still* be better smartcards?", Tamrakar et al, INTRUST 2010

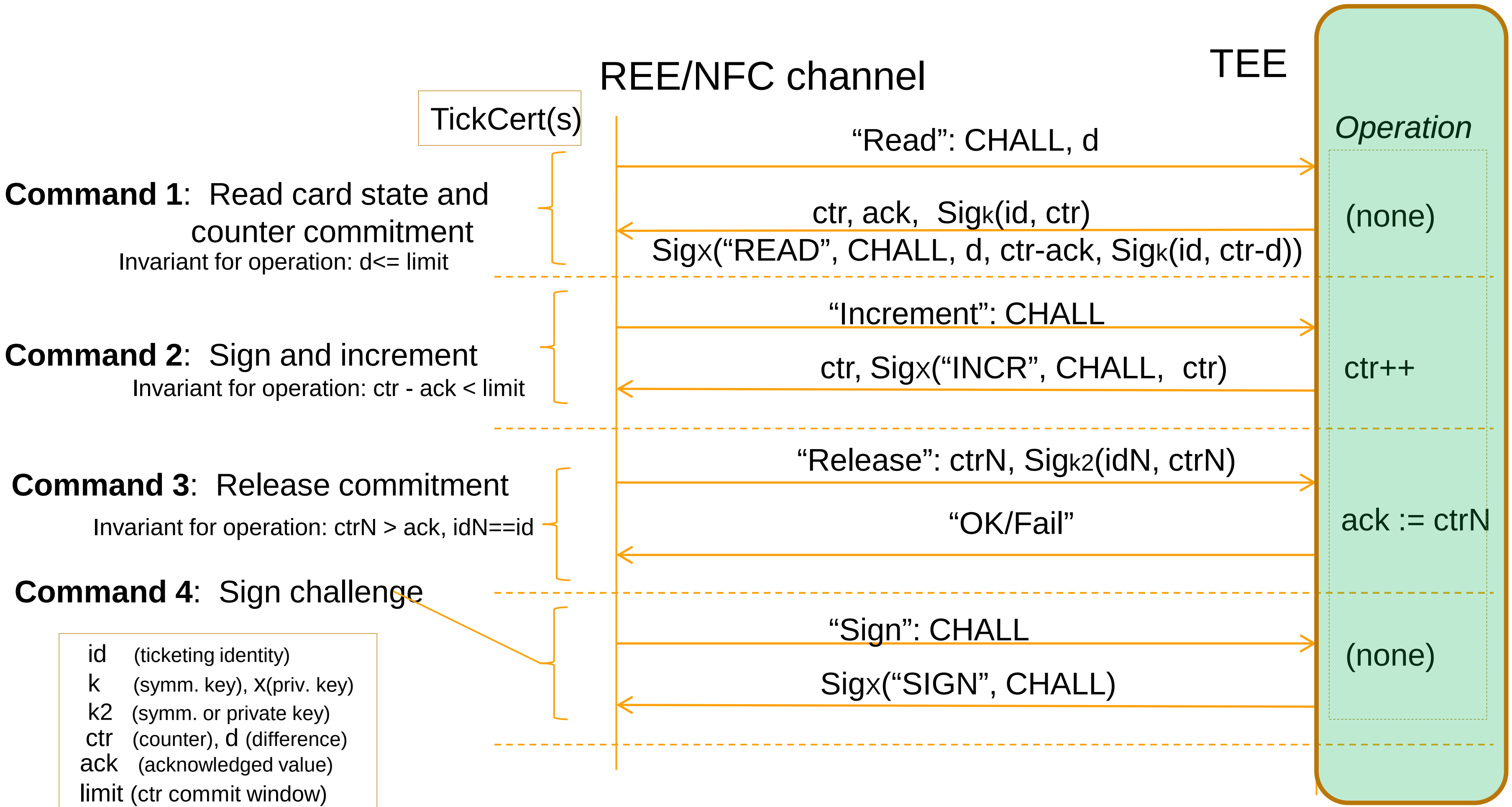
NFC Transport Ticketing

- Support ticketing in both gated and non-gated public transit systems
- Ticketing based on itinerary and identity verification
- Trial in NY MTA Long Island Rail Road



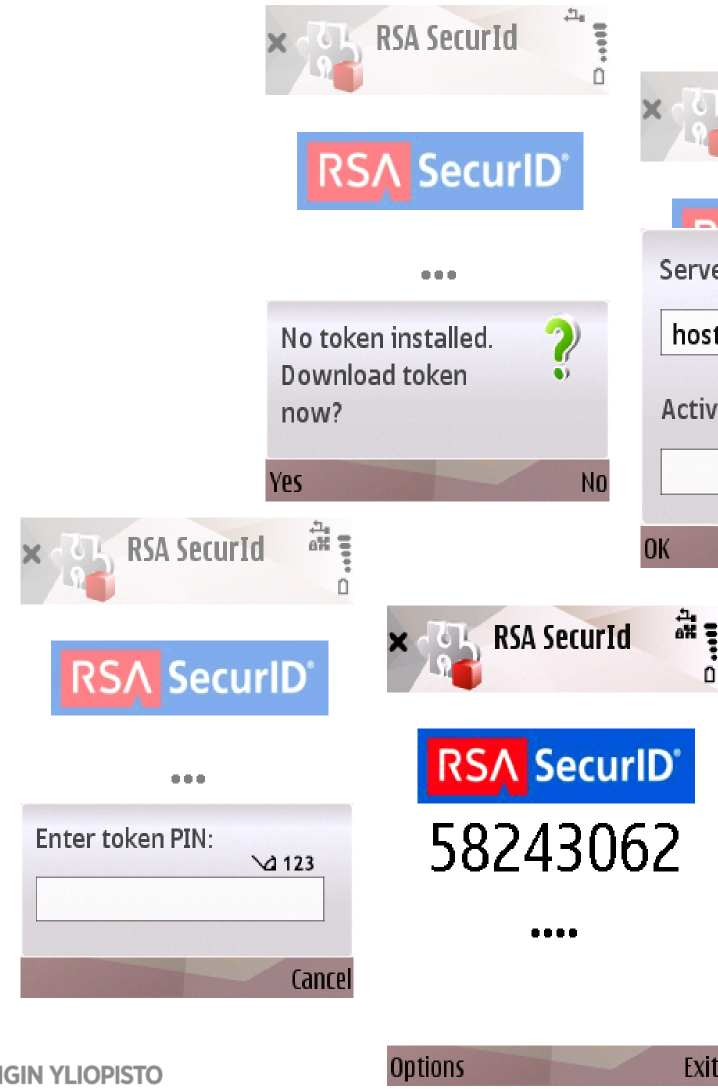
TEE support for transport ticketing

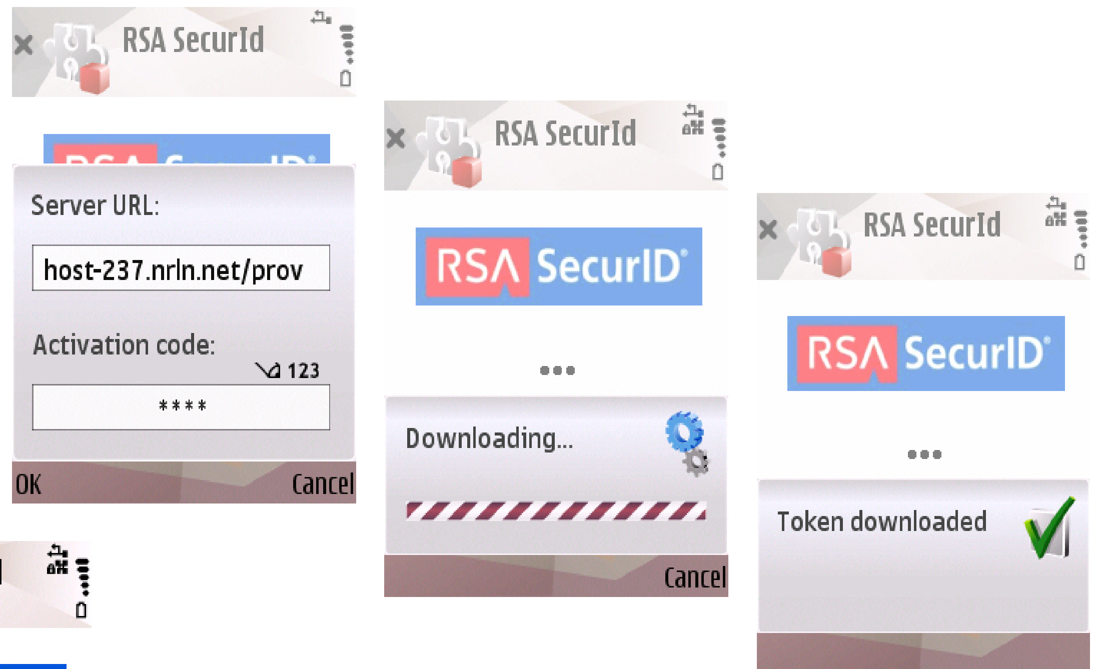
Support for managing authenticated counters implemented as an ObC program



"Mass transit ticketing with NFC Mobile Phones", Ekberg & Tamrakar, INTRUST 2011
"Tapping and Tripping with NFC, Ekberg & Tamrakar", TRUST 2013

Embedded SecurID token





Joint research project with RSA security (2008)

ObC Status

Available on off-the-shelf Nokia WP8 and Symbian devices

Development environment for ObC programs in BASIC

Credential Manager and interfaces (native, C#)

- Available from Nokia under limited license agreement for research and testing http://obc.nokiaresearch.com

More information in two dissertations:

1. 2012, Kari Kostiainen: On-board Credentials: An Open Credential Platform for Mobile Devices
2. 2013, Jan-Erik Ekberg: Securing Software Architectures for Trusted Processor Environments

Limitations

Open provisioning model

- What about liability and risk management?
- Is intuitiveness diminished?
  - e.g. User interaction for credential migration (lifecycle management)

Certification and tamper resistance

- Not comparable to high-end smart cards?

A powerful tool, but not a silver bullet

Will open-provisioning emerge as an alternative to centralized provisioning?

A Look Ahead

Standardization and Beyond

Commercial offerings starting to appear

Provide crypto API using TEE-protected keys

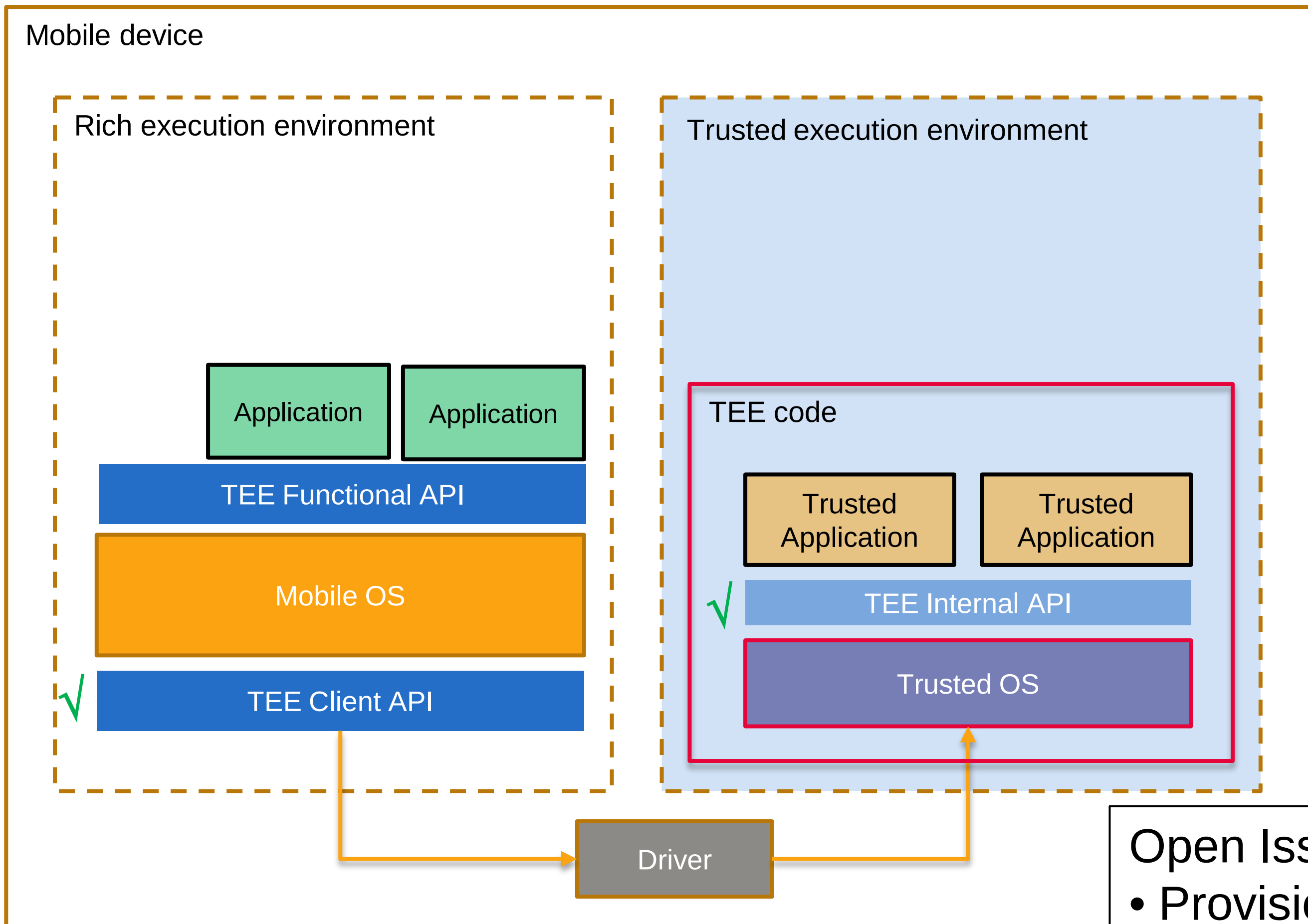
No open developer API for trusted execution, provisioning, attestation etc.?

MobiCore

Trusted Foundations

http://www.trustonic.com/

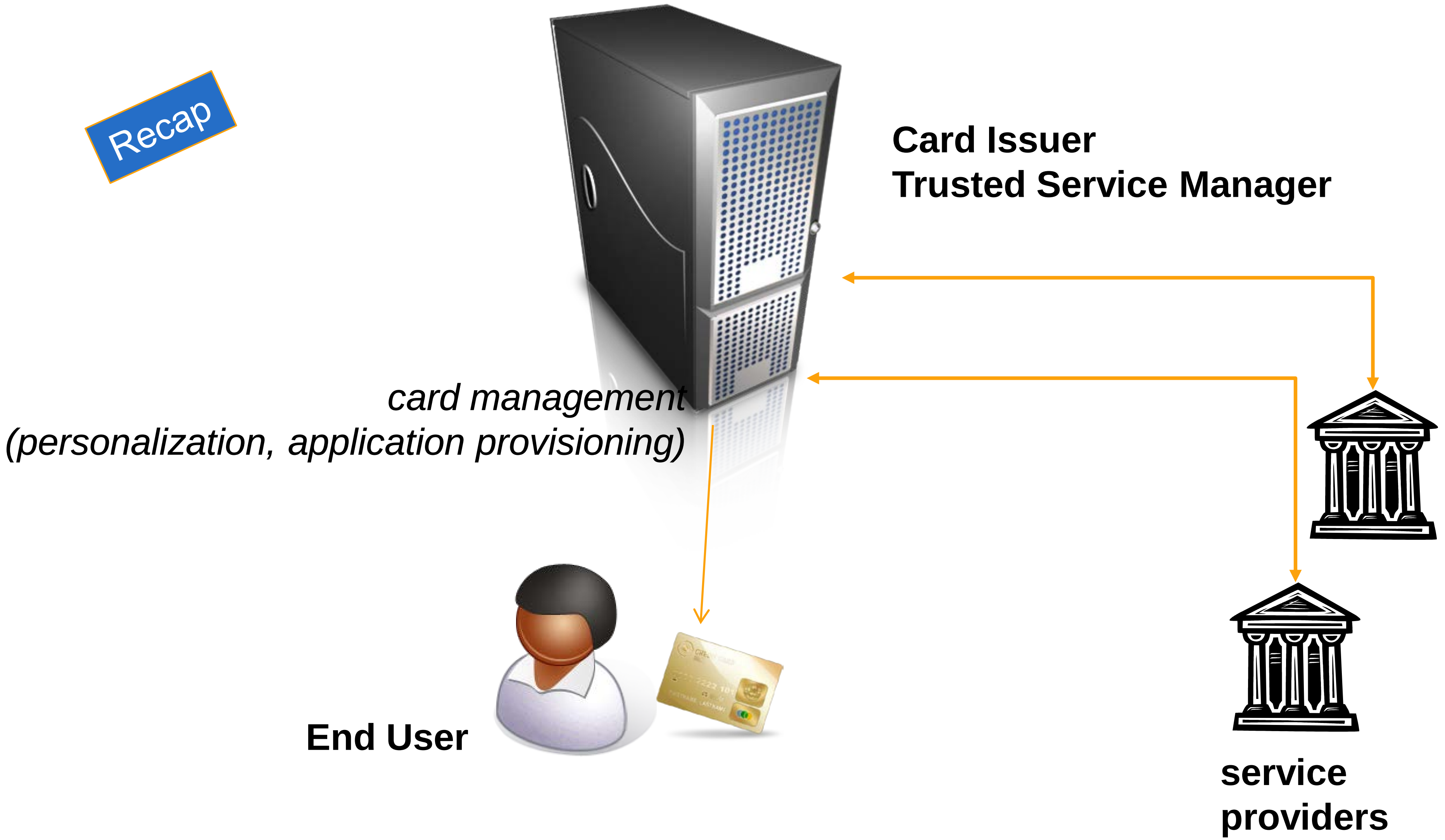
Standardization in Global Platform



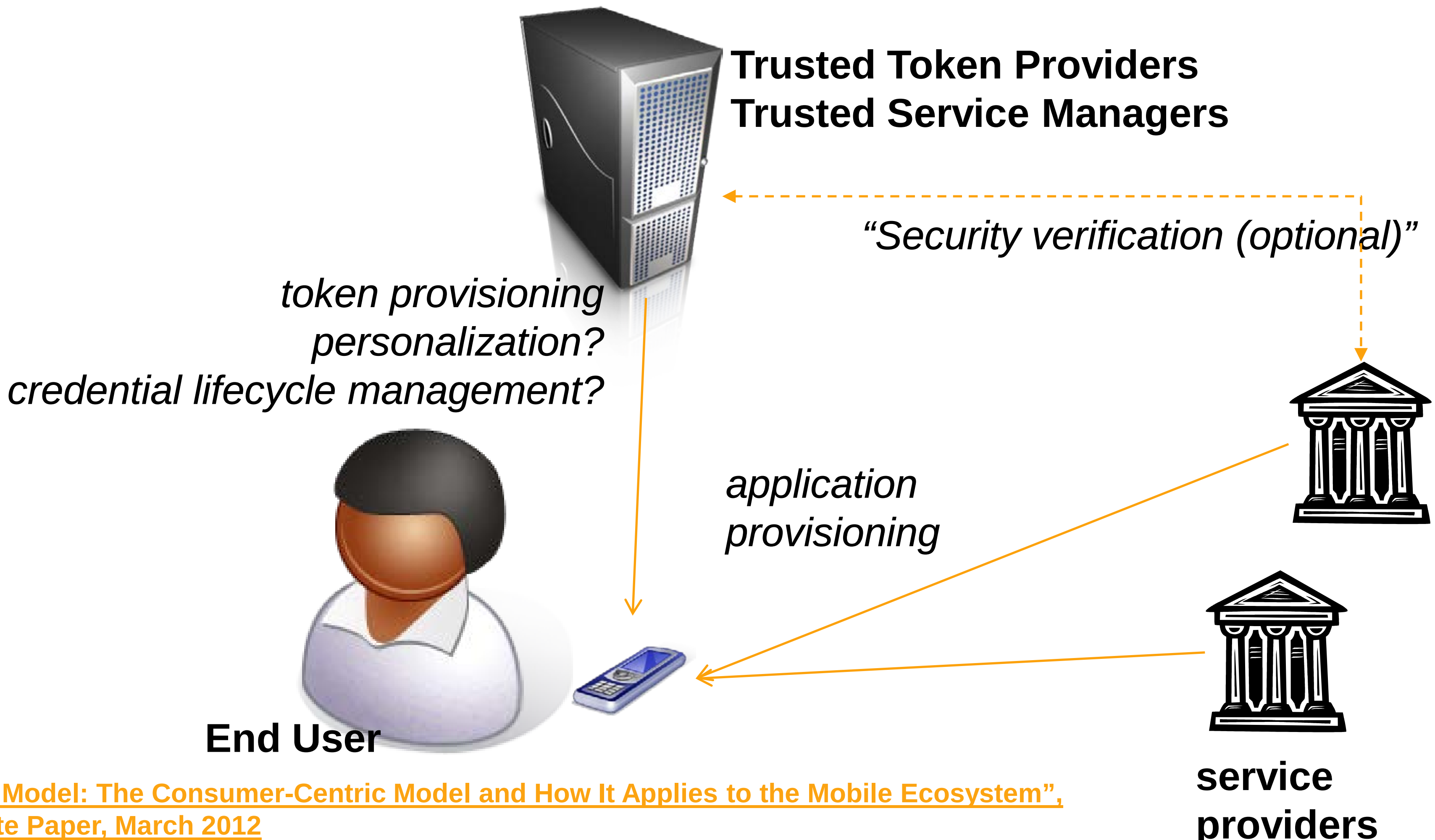
Open Issues:
- Provisioning
- TEE Functional API

http://www.globalplatform.org/specificationsdevice.asp

Issuer-centric provisioning for smartcards



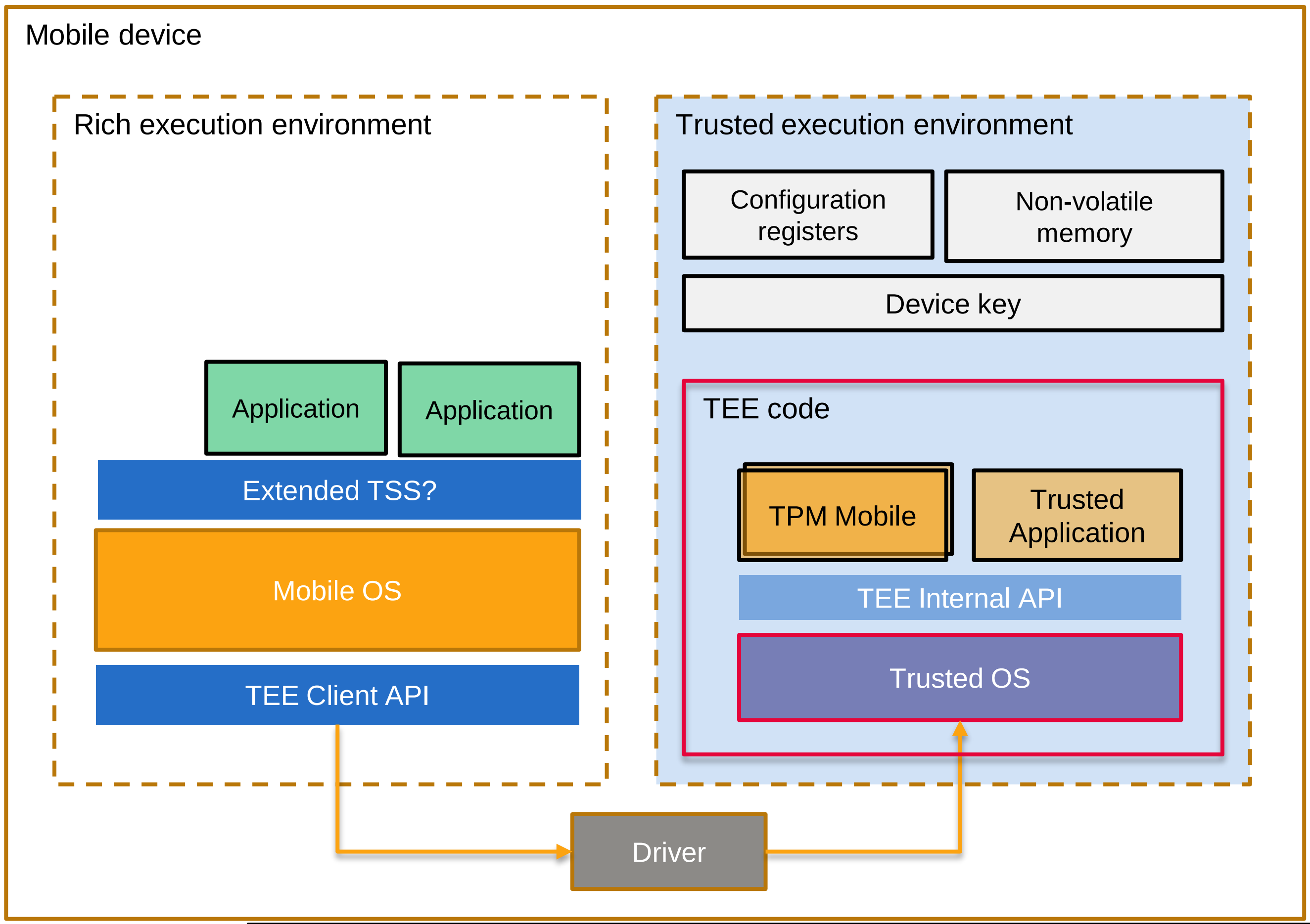
GP: Consumer-centric Provisioning vision



[**“A New Model: The Consumer-Centric Model and How It Applies to the Mobile Ecosystem”, GP White Paper, March 2012**](http://www.globalplatform.org/documents/Consumer_Centric_Model_White_PaperMar2012.pdf)
http://www.globalplatform.org/documents/Consumer_Centric_Model_White_PaperMar2012.pdf

Skip to conclusions

Best of both worlds: GP and TPM Mobile?



TEE Functional API: Extended TCG Software Stack (TSS) with support for
- provisioning
- trusted applications

making use of TPM 2 features like fine-grained access control

Summary

Hardware-based TEEs are widely deployed on mobile devices

But access to app developers has been limited

ObC: a proprietary solution to open up on-board TEE to developers

Global Platform: standardizing TEE functionality and interfaces

Will consumer-centric / “open” provisioning succeed?

“What is sauce for the goose...” Next generation mobile rootkits, BlackHat EU 2013