D03.2: Collected internal deliverables for year 1+2

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Main Deliverable

Deliverable reference number	IST-027635/D03.2/PUBLIC | 1.00
Deliverable title	Collected internal deliverables for year 1+2
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Due date	Jun 2008
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Responsible Organisation	IFX
Authors	See the cover page of each included internal deliverable
Abstract	Collection of following internal documents produced during years 1 and 2: WP03a (WP03a Overview; D03a.1; D03a.2) WP03b (WP03b Overview; D03b.1) WP03c (D03c.2; D03c.3; D03c.4; D03c.5; D03c.6) WP03d (D03d.1; D03d.2 & D03d.3; D03d.4; D03d.5)
Keywords	

Dissemination level	Public
Revision	PUBLIC | 1.00

Instrument	IP	**Start date of the project**	1st November 2005
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The Deliverable D03.2 provides you a collection of following internal documents produced from M1 to M24:

WP03a:

- WP03a Overview
- D03a.1 Functionality and Interface Specification
- D03a.2 Test Plan and Report

WP03b:

- WP03b Overview
- D03b.1 TPM Software Stack Implementation and Test Report

WP03c:

- D03c.2 High-level key manager service design specification
- D03c.3 SSL/TLS DAA-enhancement specification
- D03c.4 Key Management Adaption service code and documentation
- D03c.5 OpenSSH adaption service source code and documentation
- D03c.6 OpenSSL engine/DAA enhancement design specification

WP03d:

- D03d.1 JAVA High level overview
- D03d.2 & D03d.3 Integrated Trusted Computing into the Java Programming Language
- D03d.4 Java VM for TC implementations
- D03d.5 Java API and Library implementation

D03a WP03a Overview

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Report (see p 84/85 Annex 1 - Nature)

Deliverable reference number	IST-027635/D03a/RC|1.01
Deliverable title	WP03a Overview
WP contributing to the deliverable	WP03a
Due date	Apr 2006 - M06
Actual submission date	

Responsible Organisation	AMD
Authors	AMD (Matthias Lenk)
Abstract	Virtualization refers to the creation of one or more execution environments on the same machine each of which mirrors the original platform in order to make the respective operating system believe it was exclusively running on a real platform. This approach has several advantages over the traditional way to share the resources of a platform and enables a variety of valuable applications such as the simultaneous execution of multiple operating systems or server sharing.
Keywords	para virtualization, hardware virtualization, trusted computing base, TCB, TPM

Dissemination level	Public | Confidential
Revision	RC|1.01

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1 Secure Virtualization and Initialization Introduction

Virtualization refers to the creation of one or more execution environments on the same machine each of which mirrors the original platform in order to make the respective operating system believe it was exclusively running on a real platform. This approach has several advantages over the traditional way to share the resources of a platform and enables a variety of valuable applications such as the simultaneous execution of multiple operating systems or server sharing.

Together with hardware security features such as secure initialization this can address the vast challenge of computer security present in todays computer platforms. Potentially untrusted software or operating systems can run in a sandbox like environment with complete separation from the rest of the system.

1.1 Para Virtualization vs. full Virtualization

Without hardware support for virtualization the implementation of full virtualization, which allows unmodified operating systems to run seamlessly, proves to be complex and rather inefficient. Thus a large portion of the resources of the system are wasted for managing virtual machines.

The alternative lies in modifying the operating system for the virtual machine to reuse infrastructure of the management software called virtual machine monitor (VMM) or hypervisor. This para-virtualization leads to a significant performance improvement but incorporates the disadvantage of needing to modify the requested operating system. This is especially a problem for proprietary operating systems.

1.2 Hardware Virtualization

The traditional approach to implement virtualization are based on a complicated virtual machine monitor running on top of the operating system. In contrast to that more modern para-virtualization introduces a very thin hypervisor layer which manages the virtual machines and provides most basic operating system functionalities and an interface for the guest operating systems running inside the virtual machine.

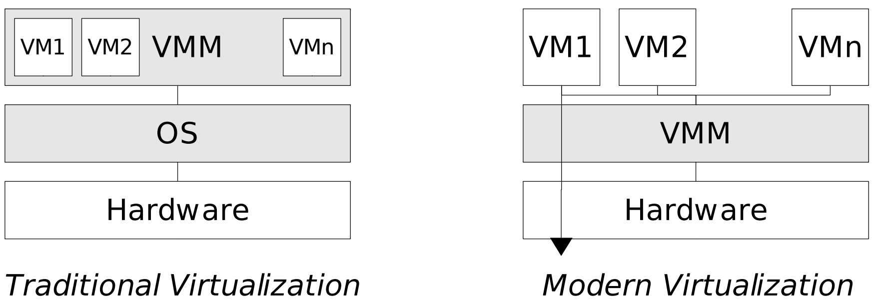

Figure 1: Traditional vs. Modern Virtualization

Hardware virtualization features can extend the hypervisor based solution by supporting unmodified operating systems and further improving performance . Thus the disadvantages of traditional and hypervisor based software virtualization can be overcome with special hardware features of the processor.

2 AMDs Secure Virtual Machine Technology

In order to support unmodified guest operating systems the AMD SVM enhanced CPU supports the new host and guest execution environments. The VMM runs in a higher privileged host mode and the virtual machines operate in a special guest mode.

2.1 Guest Execution Environment

The SVM technology provides a new CPU instruction called VMRUN which executes guest code in a secure execution environment. Whenever the guest executes an operation which requires the attention of the VMM the guest gets intercepted.

This enables secure memory partitioning by allowing the VMM to monitor the page table of the guest and to ensure strong isolation between the individual guests and host. Another cause for an intercept are interrupts and exceptions which will then be handled by the VMM. In order to let a guest handle interrupts or exceptions these events can be injected into the guest.

On each intercept the state of the guest is automatically stored in a special memory structure and recovered at the next execution.

2.2 Security Enhancements

Additional to virtualization functions the SVM technology also provides security enhancements which can be used to establish a trusted computing base (TCB). The following elements comprise the SVMs support for a TCB:

- Hardware enforced privilege levels
- Strong domain separation
- I/O protection
- Device protection
- Attestable initialization of the TCB software elements
- TPM support

The first four of these elements are directly provided by the SVM guest execution environment. For I/O port and MSR protection special bitmaps specify the privileges of each guest. Furthermore bus-master peripheral devices are prevented from accessing arbitrary memory by a mechanism called multi-domain device exclusion vector (DEV).

2.3 Secure Initialization of the TCB

Secure initialization requires immutable hardware components in order to prevent software based attacks. The new SKINIT instruction provides this immutability while retaining the ability to use traditional platform boot mechanisms. This can be achieved since uncontrolled software triggers the secure initialization process which comprises of loading a so called secure loader (SL) and TCB code into memory and executing the SKINIT instruction.

This instruction will then securely measure and start the secure loader. This measurement is extended to the TPM. It is made sure that no external hardware event can tamper with or interrupt the secure initialization process.

In the secure initialization process, the platform configuration is verified and measured. Measurements are extended to a TPM. The platform configuration includes hardware and software aspects. This allows the TCB to start in a known-good environment and to check later, if the desired configuration options are available.

The secure loader is then responsible for measuring and initializing the trusted computing base software.

3 List of Abbreviations

CPU	Central Processing Unit
DEV	Device Exclusion Vector
MSR	Machine Specific Register
OS	Operating System
SL	Secure Loader
SVM	Secure Virtual Machine technology by AMD
TCB	Trusted Computing Base
VM	Virtual Machine
VMM	Virtual Machine Monitor also known as hypervisor

D03a.1 Functionality and Interface Specification

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Report (see p 84/85 Annex 1 - Nature)

Deliverable reference number	IST-027635/D03a.1/RC|1.0
Deliverable title	Functionality and Interface Specification
WP contributing to the deliverable	WP03a
Due date	Apr 2006 - M06
Actual submission date	

Responsible Organisation	AMD
Authors	AMD (Ralf Findeisen, Matthias Lenk)
Abstract	his document specifies the architecture and interfaces for work package 03a of the OpenTC project. It is based on AMD's hardware extensions for virtualization and secure initialization.
Keywords	hardware, virtualisation, hypervisor, AMD, PCR, TPM, secure loader, configuration verifier

Dissemination level	Public | Confidential
Revision	RC1

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

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1 Scope

This document specifies the architecture and interfaces for work package 03a of the OpenTC project. It is based on AMD's hardware extensions for virtualization and secure initialization.

2 Introduction

Virtualization refers to the creation of one or more execution environments on the same machine, each of which mirrors the original platform in order to make the respective operating system believe it was exclusively running on a real platform. This approach has several advantages over the traditional way to share the resources of a platform and enables a variety of valuable applications such as the simultaneous execution of multiple operating systems or server sharing.

Together with hardware security features such as secure initialization this can address the vast challenge of computer security present in todays computer platforms. Potentially untrusted software or operating systems can run in a sandbox like environment with complete isolation from the trustworthy part of the system.

AMDs secure virtual machine (SVM) technology consists of hardware extensions for virtual machine monitors (VMM) and security enhancements of the overall x86 platform.

For support of unmodified operating systems inside a virtual machine SVM provides a new guest execution environment that enforces strong isolation between the virtual machines and the VMM. All actions of the guest OS that might comprise this isolation cause the control of the machine to be transfered back to the VMM.

In order to ensure the trustworthiness of the VMM the SVM extension provides means to establish a Trusted Computing Base (TCB) with a new instruction called SKINIT (secure kernel initialization). This instruction protects, measures using a TPM and executes a so called secure loader (SL).

3 Hardware Virtualization Abstraction Interface

The SVM technology by AMD comprises several hardware mechanisms for virtual machine monitors or hypervisors to be able to run unmodified guest operating systems. In order to reduce the effort to adapt the VMM to the new technology an abstraction layer is required which hides the complexity of new CPU instructions and structures from the VMM code.

On the other hand existing code for virtualizing components of an x86 CPU and platform should be leveraged as much as possible if they are not explicitly replaced by hardware support. Therefore this new software entity called Hardware Virtual Machine (HVM) not only provides several C functions and structures but also requires a number of C functions and structures to be exported by the VMM.

The HVM shall be responsible for running a guest inside a virtual machine, save and restore its state, handle intercepts and interrupt injection whereas the VMM remains accountable for initializing and managing guests in terms of interrupt and exception handling, shadow page table maintenance and other system services.

3.1 Overview

The HVM interface is organized as depicted in figure 1. The central element is the HVM function pointer table which contains the operations the VMM uses to access HVM functionality.

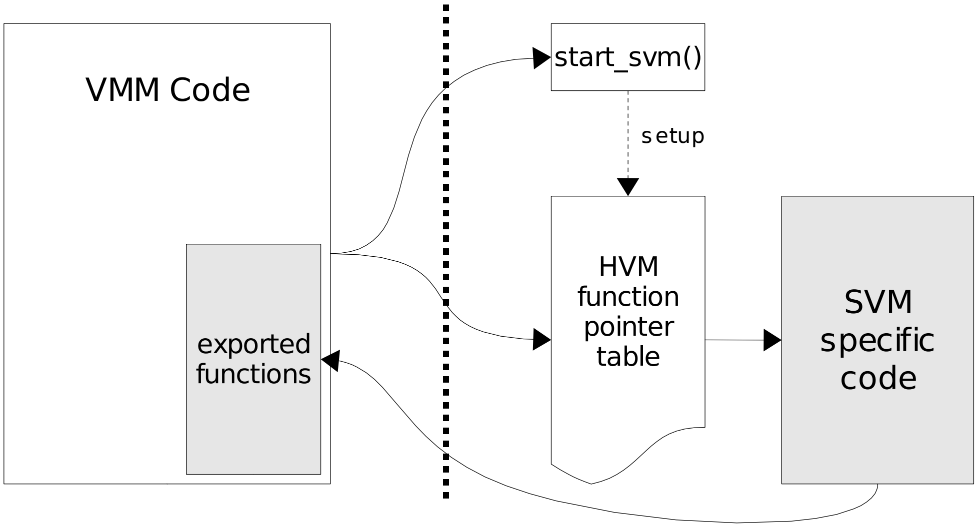

Figure 1: HVM interface overview

3.2 Interface Usage

The function pointer table is initialized by the only exported global function `start_svm()` which is supposed to be called during initialization of the VMM. This has the advantage of potentially supporting multiple different virtualization hardware extensions of different CPU vendors at compile time while retaining the original interface.

The contents of the table do not change after initialization and are valid for all virtual machines. One of the main functionalities of the HVM is running and resuming virtual machines after an intercept. Depending on the state of the guest this requires different operations when starting a virtual machine or resuming it after an intercept. Thus each virtual machine, or to be precise virtual CPU, needs its own function pointer for this operation in order to avoid too many cascaded function calls. Therefore a function pointer is added to a structure called `vcpu` which is called in case of scheduling the execution of the respective virtual CPU.

The `vcpu` structure contains VMM internal information about the virtual CPU such as scheduling information and in its architecture dependent part page tables, I/O-port access bitmaps, hardware dependent structures such as the VMCB and the mentioned function pointer for the scheduling operation. This structure is supplied to all calls to the HVM layer from VMM software.

3.3 HVM operation

The HVM layer replaces several functions usually found in the VMM. Figure 2 depicts how the devision of work between VMM and HVM code is organized.

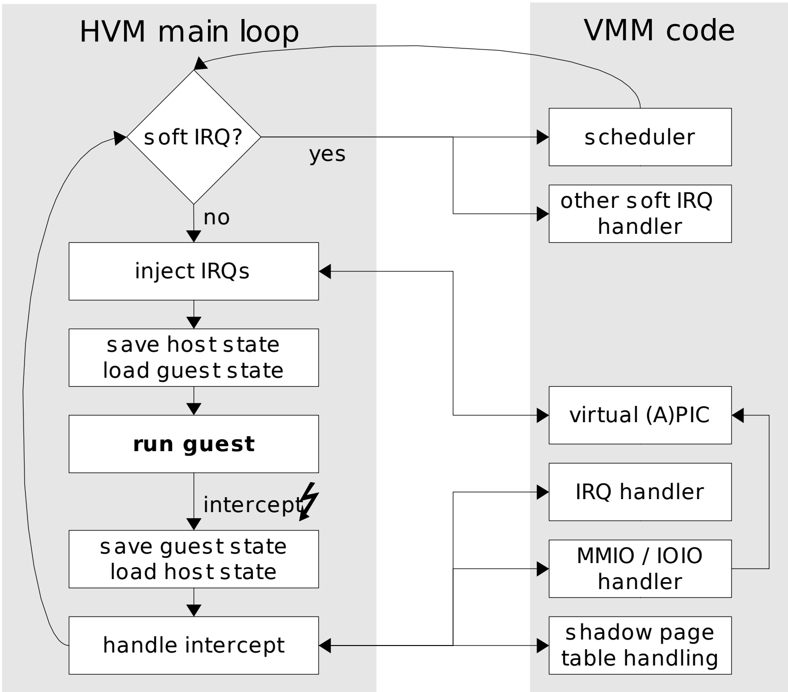

Figure 2: HVM operation

3.3.1 Running Guests

Since the actual execution of guest code is carried out in the HVM code utilizing SVMs `VMRUN` instruction the main loop of the VMM moves to the HVM code. This means the HVM saves the host (VMM) state, loads the guest state and executes the guest until an intercept occurs. After that it saves the guest state and restores the host state. It then handles the intercept and resumes the same guest again.

There are three mechanisms to interact with the VMM:

- Interrupts
- Soft interrupts
- exported functions from VMM for intercept handling

3.3.2 Handling of Intercepts

There are number of events causing an intercept of the guest that is currently running, some of which require VMM functionality. One of these are external interrupts. AMDs SVM keeps the interrupt asserted during the intercept. After the global interrupt flag has been enabled again the interrupt handler of the VMM will execute and service the interrupt. It is then up to the VMM to decide whether an virtual interrupt should be injected into the guest by programming the virtual (A)PIC accordingly.

Another important intercept is a page fault. Page faults will happen if the guest tries to modify its page table or if it tries to access MMIO address ranges that are not mapped into its address space. The HVM code has to call VMM functions to update the shadow page table and handle MMIO accesses to virtual devices such as the local APIC.

3.3.3 Interrupt Injection

Before guest code is executed the HVM has to check whether an interrupt or exception is due to be injected. In order to determine whether there is an interrupt pending it calls functions provided by the virtual (A)PIC.

3.3.4 Soft IRQs

The so far mentioned interactions between HVM and VMM are very specific and in one direction only – the HVM using VMM services. In order to provide a generic interface for executing VMM code the concept of soft IRQs has been introduced.

A special field in the `vcpu` structure points to a global structure indicating a pending soft IRQ. The HVM then calls a function `do_softirq` which can execute VMM code, e.g. for scheduling to the next guest.

4 Secure Initialization Architecture

Additional to virtualization functions the SVM technology also provides security enhancements which can be used to establish a trusted computing base (TCB). The following elements comprise the SVMs support for a TCB:

- Hardware enforced privilege levels
- Strong domain separation
- I/O protection
- Device protection
- Attestable initialization of the TCB software elements
- TPM support

The first four of these elements are directly provided by the SVM guest execution environment. For I/O port and MSR protection special bitmaps specify the privileges of each guest. Furthermore bus-master peripheral devices are prevented from accessing arbitrary memory by a mechanism called multi-domain device exclusion vector (DEV).

Secure initialization requires immutable hardware components in order to prevent software based attacks. The new SKINIT instruction provides this immutability while retaining the ability to use traditional platform boot mechanisms. This can be achieved since uncontrolled software triggers the secure initialization process which comprises of loading a secure loader (SL) and TCB code into memory and executing the SKINIT instruction.

This instruction will then securely measure and start the secure loader with the help of the TPM. It is made sure that no external hardware event can tamper with or interrupt the secure initialization process.

The software components involved in establishing a TCB are the following and depicted in figure 3:

- SL1, the 64 KB part of the secure loader executed by SKINIT
- SL2, the rest of the secure loader, measured and executed by SL1
- Configuration verification makes sure the platform configuration is in a known state by using tables which contain platform information and platform specific code

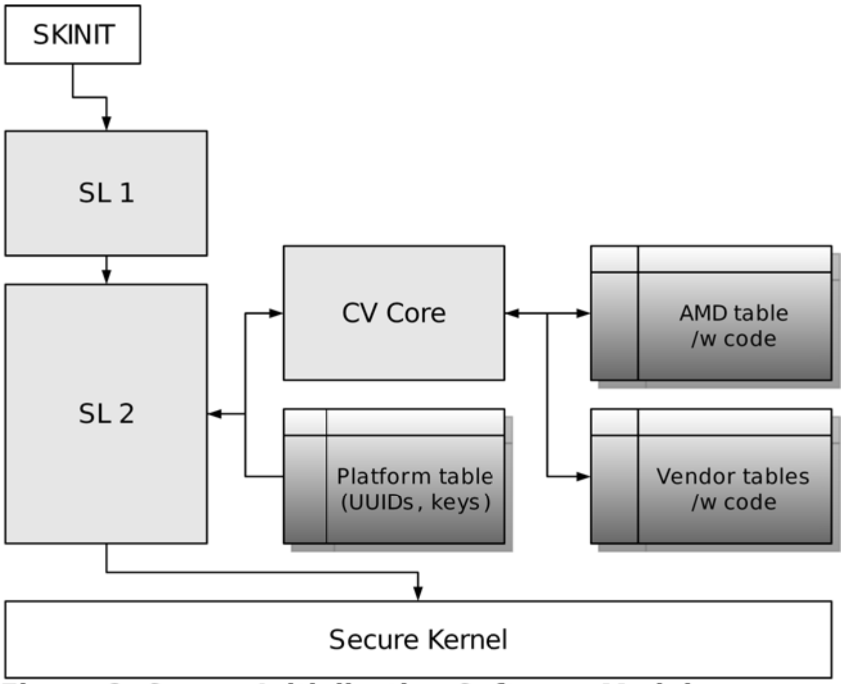

Figure 3: Secure Initialization Software Modules

The SL1/2, CV and the secure kernel have to be loaded in the untrusted portion of the boot process. After all I/O operations have been stopped SKINIT instruction is executed which then measures the SL1 using the TPM and executes it. SL1 itself only measures and executes SL2.

SL2 then measures and verifies the configuration verification core and the associated tables and executes the CV core. After the configuration has been verified the secure kernel is measured, verified and initialized.

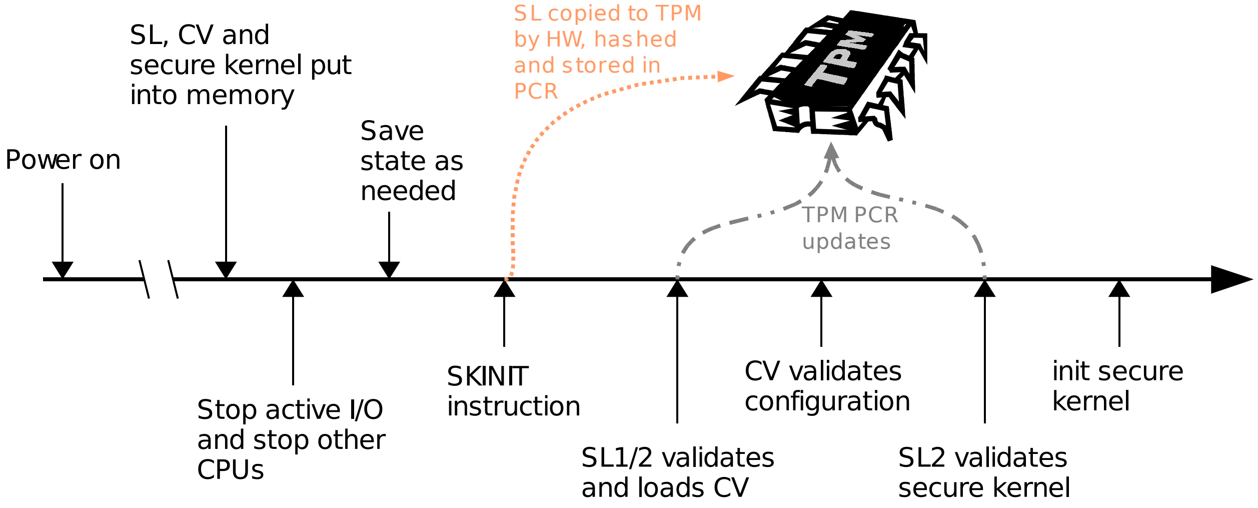

Figure 4: Initialization Sequence

5 Secure Loader

The first part of the secure loader is part of a 64 KB large structure expected by the SKINIT instruction. The so called secure loader block (SLB) contains the relative offset and size of the secure loader with its static data. The rest of the 64 KB can be used for dynamic data and stack. This memory area is automatically protected by the device exclusion vector.

Due to the limitation of 64 KB for code and data the secure loader has been split into two parts, one which resides in the SLB whereas the other is located outside the SLB.

5.1 First Stage – SL1

Due to the size limitation the responsibilities for SL1 are minimal. The following steps need to be carried out by SL1:

- Setup DEVs for SL2, CV and tables and secure kernel
- Measure SL2
- Extend to TPM
- Jump to SL2. The address of SL1 is supplied as argument

The SL is executed in 32-bit flat memory model with paging disabled. The processor is in a state equivalent to the state usually caused by INIT signal. All interrupts including non maskable interrupts and exceptions are disabled by clearing the global interrupt flag introduced with SVM.

The dynamic data section at the top of the SLB contains the following information prior to the execution of SKINIT:

- The saved state of the boot loader which executed SKINIT (optional)
- The addresses and sizes of the other code blocks, SL2, CV, secure kernel
- Pointers to the CV and platform tables

5.2 Second Stage – SL2

Since there is no 64 KB limitation on the size of the SL2 more code, e.g. for verifying signatures, can be included. The following tasks need to be carried out by SL2:

- Measure CV core and extend to TPM
- Verify CV core signature
- Measure platform table and extend to TPM
- Verify platform table signature
- Retrieve UUIDs and keys from platform table
- Find AMD and vendor tables
- Measure tables and extend to TPM
- Verify table signatures
- Invoke CV and pass pointers to verified tables
- Measure secure kernel and extend to TPM

- Optionally verify kernel signature
- Jump to secure kernel entry point

The addresses and sizes of the code blocks and tables are retrieved from SL1 runtime data area.

6 Configuration Verifier

The Configuration Verifier (CV) engine measures and verifies components of a platform. These parts can be software or hardware components.
CV is composed of a CV core, which contains the operation code and the some tables with data to describe platform, vendor and AMD components.
This section describes the architecture and gives an implementation overview of both.

6.1 CV Core

The CV core is the operation engine for the tables. CV core is measured and verified by SL2 before it is executed. Therefore it is trusted code. SL2 has already setup DEVs for the core and its tables.

CV core gets the information, where to find all tables passed from SL2 in a list of pointers. Each table can be uniquely identified by a UUID. The Platform-Table contains identification information for all other tables.

After reading the platform information, the core takes the Vendor-Tables in the order they are listed in the Platform-Table and executes the measurement operations listed there (top to bottom). Each measurement operations produces a measurement of some platform aspect, which is passed back to the core. The tables also contain expected answers, so that the result can be compared for correctness.

If an incorrect result is found, the processing of tables in the core stops immediately and execution is passed back to SL2 with an error indication. It is expected, that the secure startup is ended then and the secure kernel will not be loaded.

6.2 CV Tables

The CV core operates on different classes of tables. From each at least one is available on a system. The tables classes are:

- Platform tables
- Vendor tables
- AMD tables

The format of configuration tables is defined in figures 6 and 7. Tables are compiled using preparation tools in user mode on a platform and delivered on regular software distribution ways (e.g. system delivery, online update, disks).

To ensure the integrity of a table and to authenticate it, tables are signed by either the platform authority or one of the vendors (including AMD). When CV is called, SL2 has already done the verification and authentication and has extended the PCRs for the tables. CV core assumes *good* tables!
CV tables are standalone. They are not linked. Tables are identified using UUIDs as specified in RFC 4122. The information to find the tables is passed to SL1 at start time. The platform table identifies the other tables.

Platform Table
The platform table is the master table. It contains the description of a whole setup, e.g. a server configuration.

The platform table holds the UUIDs and respective public keys for all vendor tables. This includes AMD and other hardware vendors. The table can also have information about the software environment starting on the platform.

There is only one platform table. The platform table can be identified by reading the platform model number field. This field needs to be zero in all other tables.

AMD and Vendor Tables
Vendor tables are associated with a certain component vendor for a platform. It contains code and verification information for the vendor's parts on a platform.
The verification process uses vendor specific measurement operations to measure hardware. They are organized in entries in the table, so that each measurement operation can be uniquely identified by a UUID and has an expected result and a code snippet to be executed to get a result from the platform.

Only when expectation and result match, a positive result is given back to the core.

Code Snippets
Code snippets are position independent pieces of code, which are executed from CV core to measure parts of the platform. A flat 32 bit execution environment is to be expected. The format is similar as SL1, with a field for the overall length followed by an entry point, which specifies the offset from the beginning of the code snipped (including length and entry point field).

The code snipped is invoked via CALL instruction which means the code snippet needs to return as if it was a regular function.

7 Memory Organization

All code and data are delivered as static binaries which implies all code has to be position independent and written for flat 32-bit mode.

The binaries for SL1, SL2, CV and the related tables and secure kernel have to be loaded prior to SKINIT execution to an arbitrary memory location below 4 GB. Each of these modules has to be physically continuous in memory and SL1 has to be 64 KB aligned.

A physically continuous DEV bitmap has to be allocated by the loading entity which will then be overwritten by SL1.

7.1 Code Modules Memory Layout

The secure loaders and CV modules have the layout depicted in figure 5.

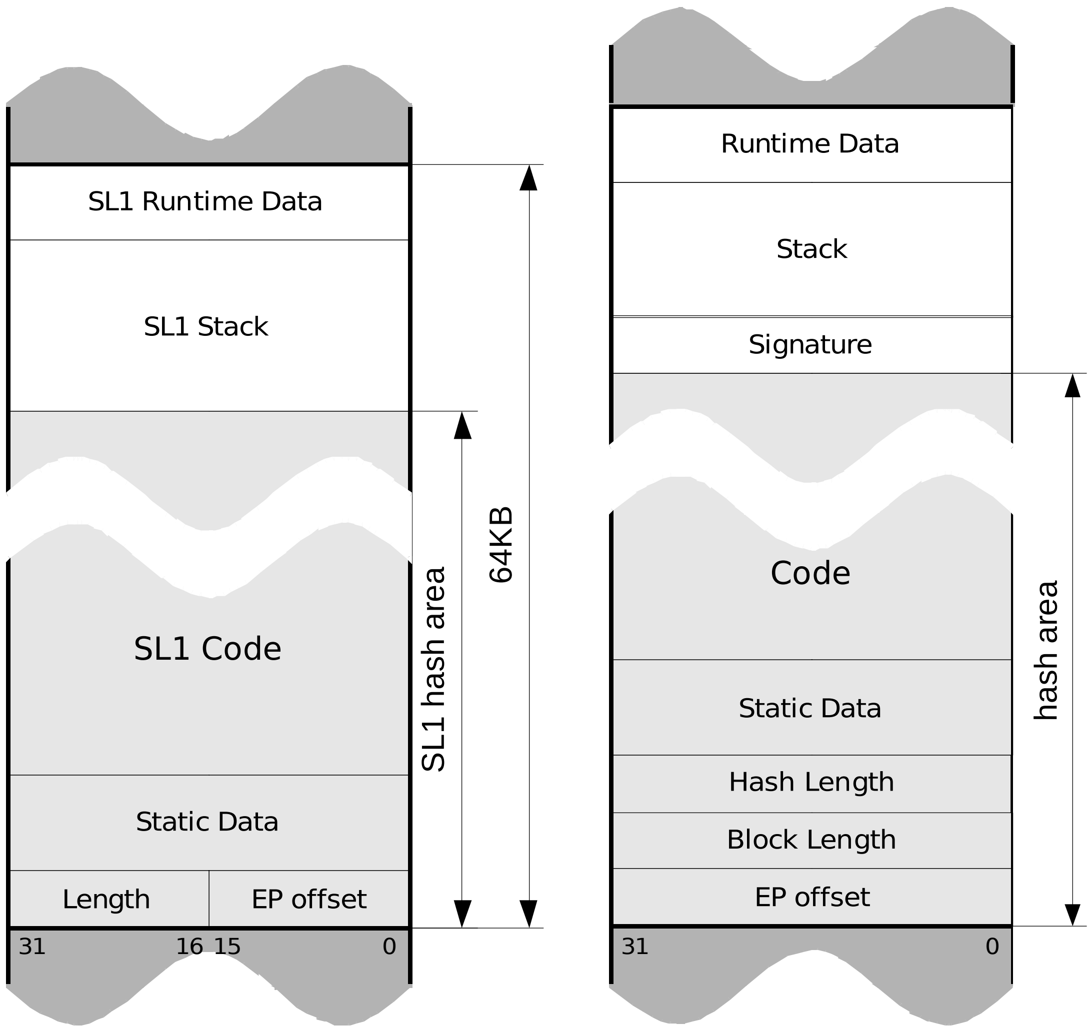

Figure 5: Memory structure of SL1 (left), SL2 and CV (right)

Each of the modules begins with length information of the to be hashed area and entry point information. SL2 and CV additionally contain block length information. Static data, e.g. keys, are located between this header information and the code. For signed modules the signature is located behind the code. Runtime data and stack form the rest of the module.

7.2 SL1 runtime Memory

The contents of runtime and static data of SL2 and CV and static data of SL1 are implementation dependent the runtime data of SL1 requires a specified structure due to the fact that SL1 and the successively executed components require information about the location and size of the components supplied by the loader.

Table 1 lists the elements stored in the runtime data section of the SLB. Note that the offsets count from the end of the data block.

Field	***Offset***
SL2 address	0
SL2 size	-4
CV address	-8
CV size	-12
SK image address	-16
SK image size	-20
SK multiboot structure address	-24
DEV address	-28
Platform table address	-32
AMD table address	-36
Number of Vendor tables	-40
Vendor table 1 address	-44
...	
Vendor table n address	-44 + 4 * (n – 1)
Scratch pad	-44 + 4 * n
State information (registers, MSRs, ...) of loader (optional)	-1024

Table 1: SL1 runtime data contents

7.3 Table Format

The following figures specify the structure of platform and vendor tables to scale.

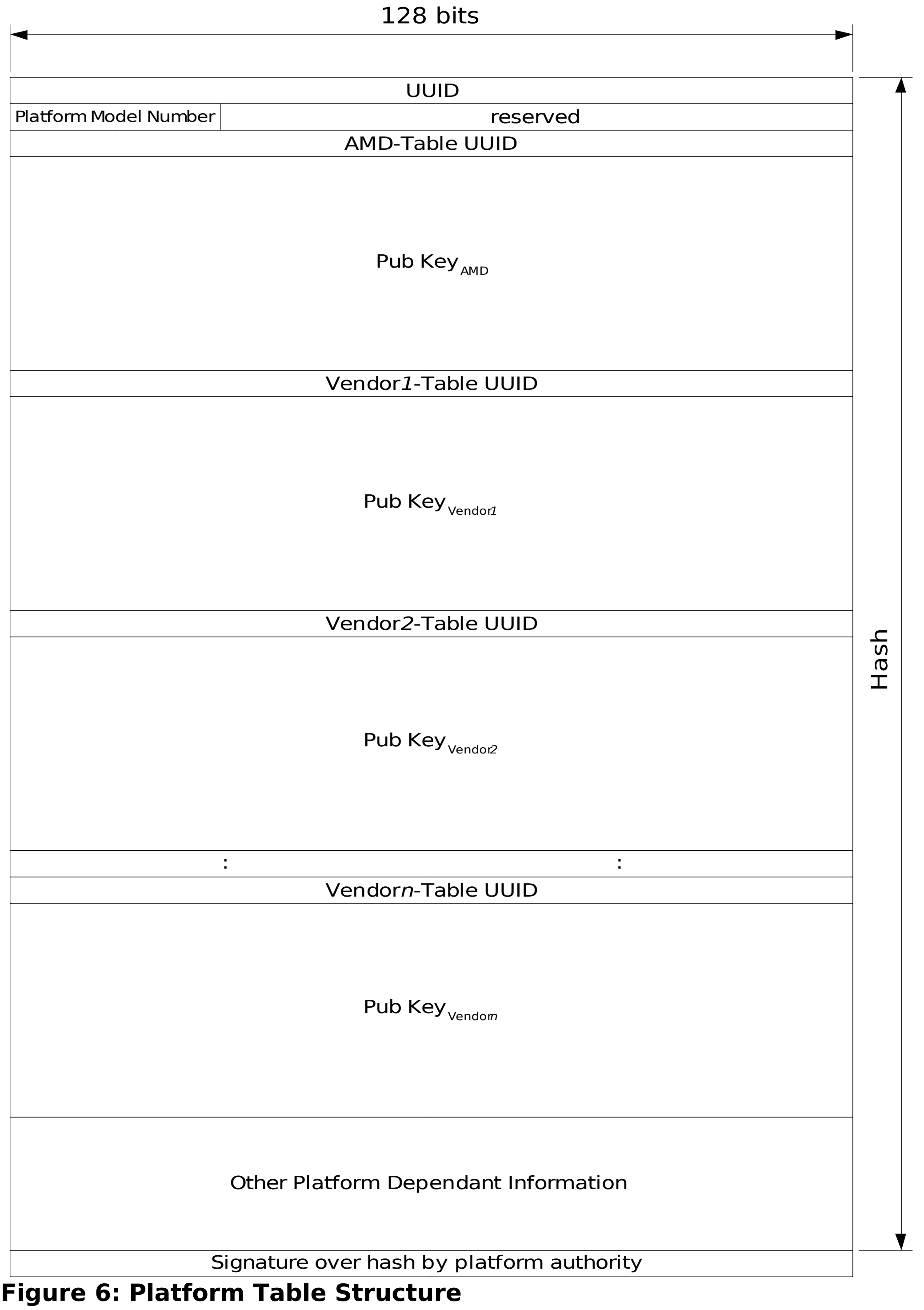

Figure 6: Platform Table Structure

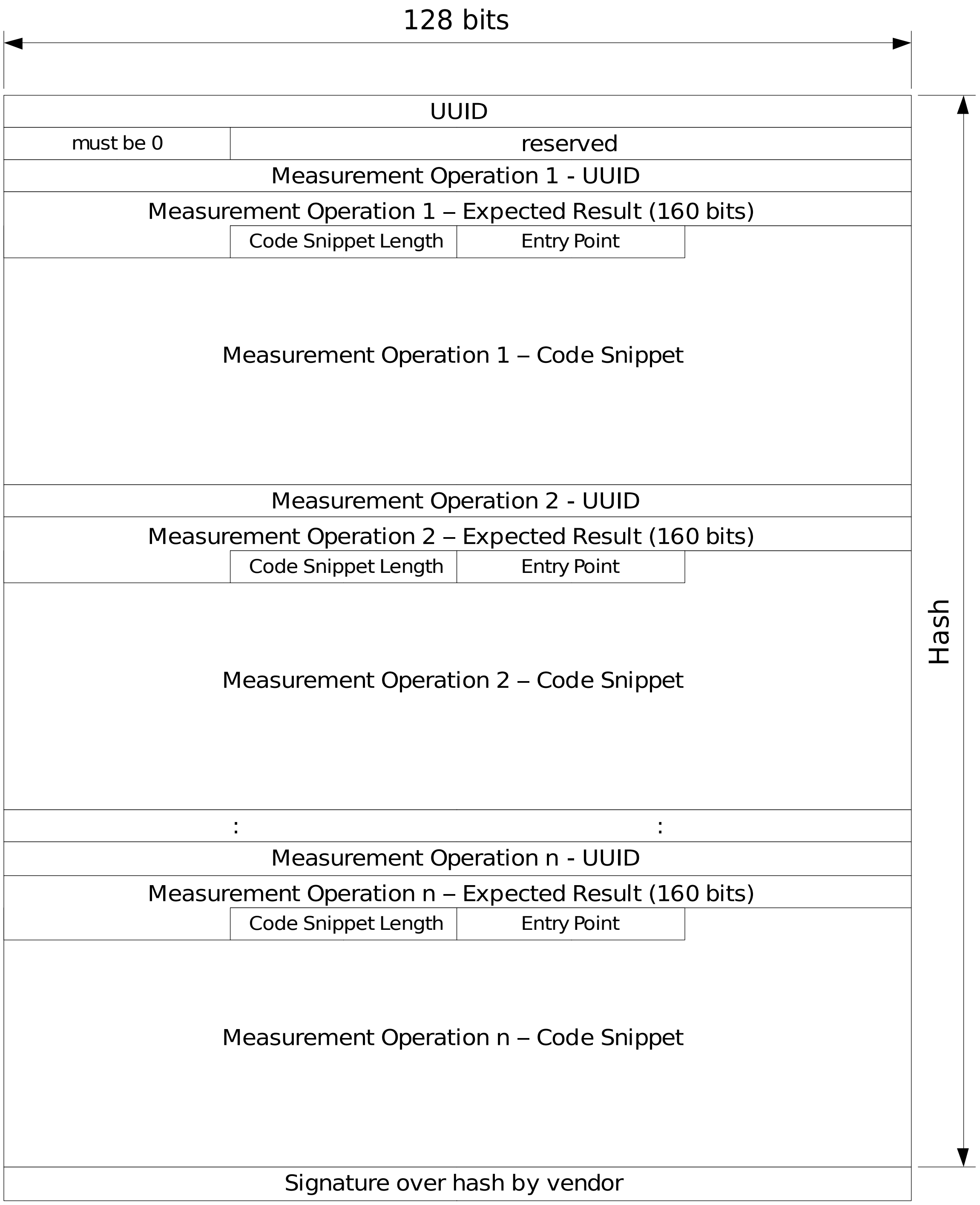

Figure 7: Vendor Table Structure

7.4 PCR Usage

The measurement of particular components is bound to certain PCR registers in the TPM. The SKINIT hardware writes the measurement value into locality 4 which corresponds to PCR #17. Figure 8 depicts which component measurement extends to which PCR registers inside the TPM for later attestation.

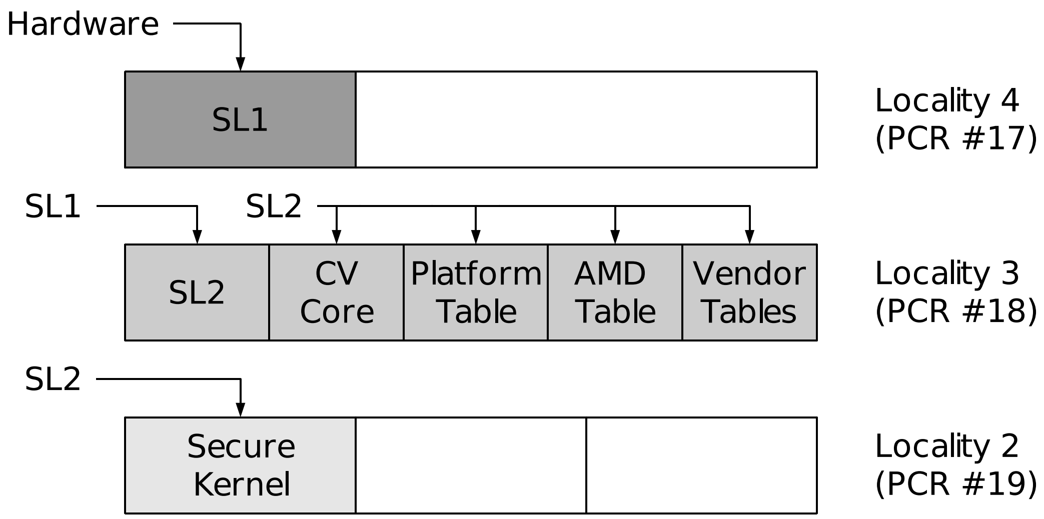

Figure 8: PCR Usage for Secure Initialization

D03a.2 Test Plan and Test Report

Project number	IST-027635
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Deliverable type	Report (see p 84/85 Annex 1 - Nature)

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Responsible Organisation	AMD
Authors	AMD (Ralf Findeisen, Matthias Lenk)
Abstract	This document specifies the test plan and test report for work package 03a of the OpenTC project. It describes the tests to be implemented and executed to verify the correct operation of the secure startup software solution provided by AMD. The environment is defined and the test cases in categories of their scope are defined.
Keywords	DRTM, TCB, Trusted Computing base, Secure loader, test plan, test report, Virtualisation

Dissemination level	Public | Confidential
Revision	RC|1.01

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Thematic Priority	IST	**Duration**	42 months

Table of Contents

1 Scope

This document specifies the test plan and test report for work package 03a of the OpenTC project. It describes the tests to be implemented and executed to verify the correct operation of the secure startup software solution provided by AMD. The environment is defined and the test cases in categories of their scope are defined.

2 Introduction

The main purpose of the secure initialization solution provided by AMD is to establish a dynamic root of trust for measurement (DRTM) and on this basis initialize the trusted computing base (TCB). Furthermore the configuration of the system it is running on is verified.

The components of the system comprise of a secure loader (SL) which consists of two parts, a configuration verification engine (CV) and tables which contain verification code and information about the platform which is being verified.

The SL1 is executed by a new CPU instruction called SKINIT. This instruction creates an immutable execution environment for the first part of the secure loader. The secure loader then sets up the memory protection called device exclusion vectors (DEV) and measures and executes SL2. SL2 checks signatures of the CV core and supplied tables. It then calls the CV to execute and analyze the tables presented.

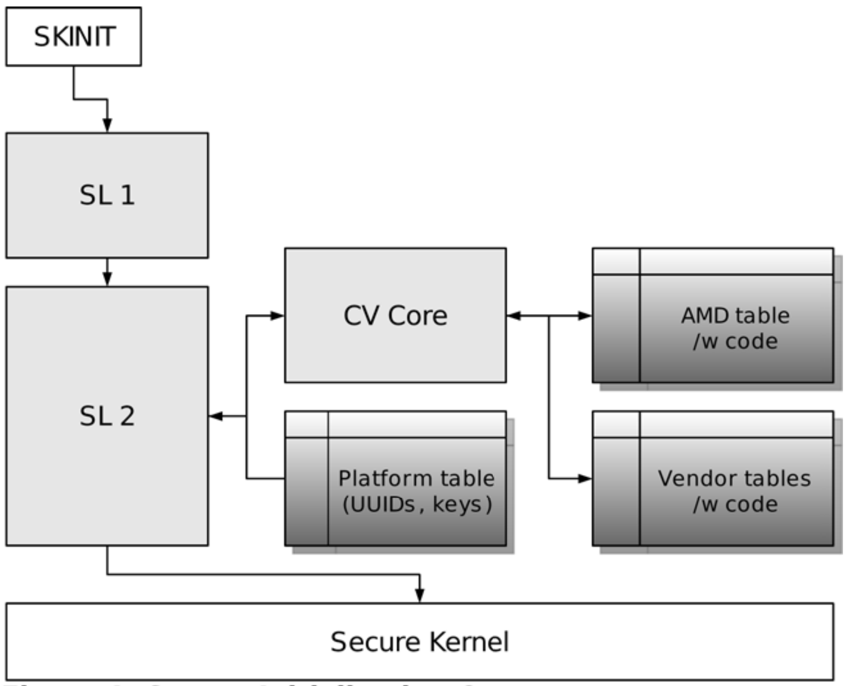

Figure 1: Secure Initialization Components

After CV finished the secure kernel (SK) is executed. All components involved are measured and extended to the TPM.

3 Test Environment

The tests for the secure initialization software are organized in categories unit tests, component test and system tests. Unit tests are carried out on the host or development system whereas component and system tests have to be carried out on the target system. Some components or some aspects of components can only be tested on the target since they require special hardware not usable on the development system.

3.1 Unit Test Environment

Unit tests are written in special test programs that test individual functions of the to be tested component and are separate from code running on the target.

Execution environment	Linux (x86 or x86_64), user space process
Compiler tool chain	gcc 32-bit x86 version 3.3 or higher, OpenSSL
Hardware	Any x86 machine Pentium/Athlon class
User Interface	bash command line

Table 1: Unit Test Environment

Unit tests programs shall generate a test report as its output which indicates whether each test has failed or succeeded.

3.2 Component and System Test Environment

Component and system tests have to be carried out on the target system. The test routines shall be embedded in the target software and shall report its success on the text mode screen due to the lack of disk access.

Hardware	Revision F Opteron/Athlon 64 Infineon TPM SLB9635TT1.2
Execution Environment	32-bit flat mode, running from grub2 boot loader
Compiler tool chain	gcc 32-bit x86 version 3.3 or higher
User Interface	grub2 console VGA text mode

Table 2: Component and System Test Environment

Grub2 boot loader is used to load and execute the secure initialization software.

4 Unit Tests

The following sub sections list unit test cases ordered by functional block. Each test is specified by a name, its operations and expected result.

The tests of each block are organized in one test program.

4.1 Big Number Library

The big number library is used for RSA signature verification and CV table signature generation.

Test	*Operation*	*Expected Result*
Multiply 1	multiply p and q from RSA test vectors PSS-INT	n from RSA test vectors PSS_INT
Multiply 2	multiply two random number a and b. Calculate the modulo of the result c with b. Repeat with a = c until maximum size of big number is reached	The big number zero for (c mod b) in all iterations
Modulus 1	Take q, qInv, p from RSA test vectors PSS-INT. Calculate (q * qInv) mod p	The big number one
Modulus 2	Take e, dP, p from RSA test vectors PSS-INT. Calculate (e * dP) mod (p – 1)	The big number one
Modular Exponentiation	Take S, n, e from RSA test vectors PSS-INT. Calculate (s^e) mod n	EM from RSA test vectors PSS_INT

Table 3: Big NUmber Library tests

4.2 RSA signature verification generation

The RSA code uses the big number library to calculate the fundamental RSA operations.

Test	*Operation*	*Expected Result*
Signature verification 1	Generate key pair and signature of SL1 binary using OpenSSL. Read public key, SL1 binary and verify signature	Signature being verified
Signature verification 2	Use signature and key from test above and flip a random bit in the signature. Verify signature	Signature NOT being verified
Signature generation	Use key pair from test above. Read private key and sign SL1 binary. Verify signature	Signature being verified

All test have to be repeated for keys of 512, 1024, 2048 bits size.

4.3 SHA1

The SHA1 algorithm is used to measure loaded components of the secure initialization process.

4.4 DEV

DEV maps are used to specify memory protection from external devices.

Test	*Operation*	*Expected Result*
Random block	Block random address range (< 4GB) in DEV	Bits for address range being set
8 byte block	Block address ranges from 1 to 7 bytes in size each with (address mod 8) = 0, ..., 7 starting with an empty (all zero) vector	Bits correctly set
Block/Unblock	Block random address range (< 4GB) in DEV and unblock the same range	Empty vector (all zero)

5 Component Tests

Component tests are manually carried on the target system and report success or failure on the text mode screen during the execution of the secure initialization software. The software has to be recompiled for each test since specific test code will be included.

5.1 Secure Loader (1 / 2)

Test	*Description*	*Expected Result*
SKINIT	Execution reaches SLB	Text message indicating code execution of SL code
SKINIT 2	Check TPM PCR 17 after SKINIT execution	Correct hash value in PCR 17
SL2	Execution reaches SL2	Text message indicating code execution of SL2 code
TPM Access 1	Register Access to TPM	Text reporting correct DID/RID of TPM
TPM Access 2	Use TPM extend operation to hash SLB as the SKINIT instruction would into PCR 19	Identical values of PCR 17 (from SKINIT) and PCR 19
DEV setup	Test DEV settings using external hardware for bus master memory access while SL code is deliberately stopped.	All memory accesses to protected memory shall fail. Memory accesses outside memory protection shall succeed

Test	Description	Expected Result
CV	Execution reaches CV while tables are present	Text message indicating code execution of CV code

5.2 CV

Test	Description	Expected Result
Platform Table	Platform table signature verification of correctly signed table in memory	Signature should be verified
Platform Table 2	Platform table signature verification of incorrectly signed table in memory	Signature verification shall fail
Vendor Table	Execute a variable number of no-op vendor tables that always return correct result	All vendor tables executed and verified
Vendor Table 2	Execute a variable number of no-op vendor tables that always return correct result, except one whose signature is corrupted	Configuration verification stops at corrupted vendor table
Vendor Table 3	Execute a variable number of no-op vendor tables that always return correct result, except one which always return incorrect result	Configuration verification stops at failing vendor table

6 System Tests

System tests use the secure initialization software in its complete form without any test code included.

Test	Description	Expected Result
Boot L4	Boot a simple L4 system comprised of Fiasco kernel and hello world application	System boots L4 fully functional
Boot Xen	Boot Xen kernel plus initrd	System boots Xen fully functional
Verify L4	Boot L4 system and verify TPM PCR values	PCR values identical to precomputed values
Verify Xen	Boot Xen system and verify TPM PCR values	PCR values identical to precomputed values

D3b WP3b Overview and TPM Software Stack

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Report (see p 84/85 Annex 1 - Nature)

Deliverable reference number	IST-027635/D3.1/RC1
Deliverable title	WP3b Overview and TPM Software Stack
WP contributing to the deliverable	WP3
Due date	JUL2007
Actual submission date	

Responsible Organisation	IFX
Authors	IFX (Hans Brandl)
Abstract	The main specification of the TCG defines a subsystem with protected storage and trust capabilities: The Trusted Platform Module (TPM). For translating the low level functionality fo the TPM security chip to a high level API, the TCG standardized the so called TPM Software Stack (TSS). Within this deliverable a TSS was implemented according of the TSS1.2 specification of the TCG. This report describes the method of implementation and also the test procedures during the development process as well as a third party test of the finished product.
Keywords	TPM, TSS, TSPI, TCG, Trust, Security, Tes

Dissemination level	Public
Revision	RC1

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

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1 Development Environment Workpackage 03: Basic Interfaces and Trust Layers

This WP contains the interfacing of the trusted computing hardware elements to the requirements of unified SW APIs. We separating the functions of the platform's enhanced main processor, security module (TPM) and relevant peripherals from the required abstract SW layer. All these modules are part of the WP3.

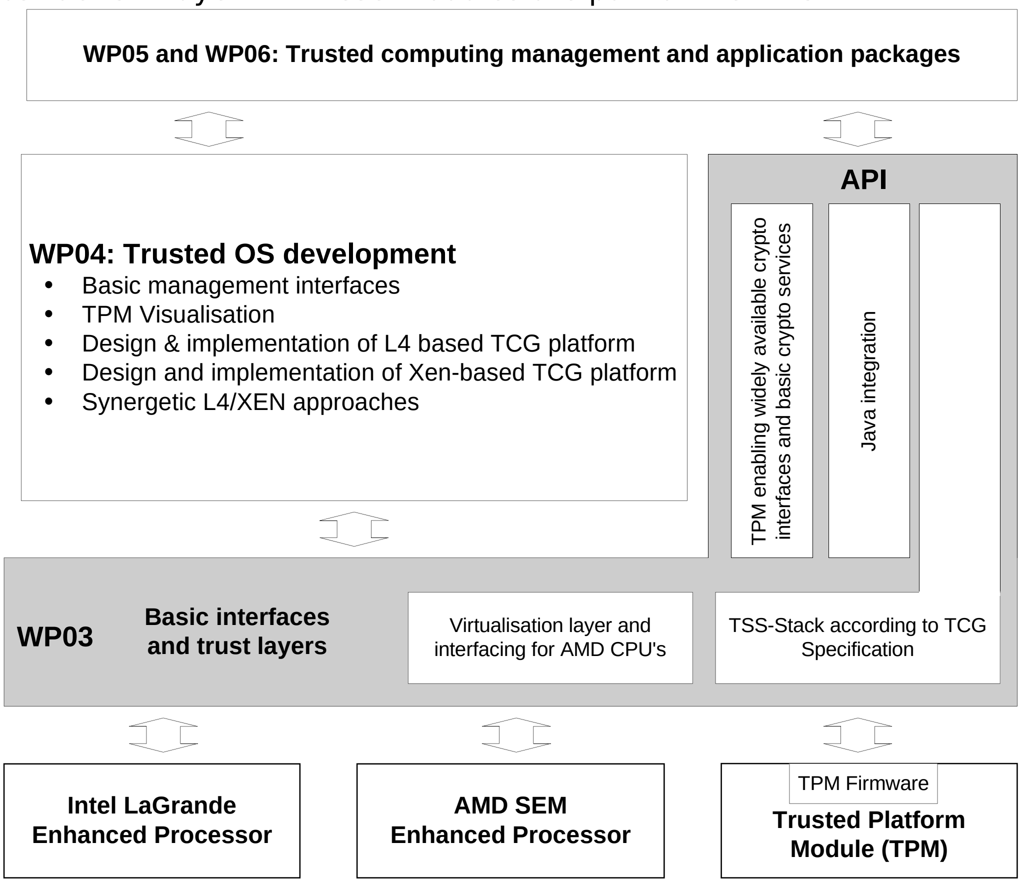


Figure 1: Workpackage 03 structure

Main Activities:

a) TC enhanced CPUs:

Intel's Vanderpool processor technology and AMD's Pacifica processor will both contain TC enhancement features and offer an additional interface with allows virtualization. Virtualization is proving to be an ever-more useful tool to solving problems ranging from trusted computing to VLIW migration to distributed computing. Used to migrate resource management into user space or encapsulate runtime environments, new virtualization developments promise to dramatically affect our use of computers in the near future.

Virtualization allows also a far better implementation of the security and protection features which are necessary for trusted computing hw support. Programming jobs in all OS get a lot easier with virtualization support built directly into the processor.

Within Open_TC we support both processor vendors for allowing a broad and universal access to TC on all standard platforms:

- **Intel**
  Intel has already a cooperation with the Open_TC partner CUCL, where the CPU hardware requirements for TC and also the basic virtualization needs are handled in a different open Source project. Within Open_TC we will use these results which are available also in detail via our partner CUCL. Therefore no special Intel package is required, however all the necessary data and code will be accessible.

- **AMD**
  AMD will provide support to adapt the trusted OS layers to the AMD Pacifica processor virtualization extensions and Presidio platform-level security extensions according to the requirements determined in month 1 to 6. In particular, this concerns the development of a CPU hardware interface layer and a low level virtualization with security package, allowing for easy use and development of this new technology to support TC issues.

b) TCG Software Stack (the TSS)
The TCG Software Stack (the TSS) is the supporting software on the platform supporting the platform's TPM. Its specification was done by the TCG and is publicly available at the internet at [TCG05]. Within the project we will adapt the TSS to the requirements of Linux , L4 and XEN trusted OS.

c) TPM-enabling widely available crypto interfaces and basic crypto services
OpenSC, OpenSSL and OpenSSH are widely used and deployed, full-strength general purpose, open source solution packages and crypto library. Therefore we will also integrate an adaptation software module by which the cryptographic features can securely processed via the TSS stack in the TPM crypto module. This enables it to use the TPM as a protected storage for keys and as a hardware crypto device. Furthermore a PKCS#11 module and an adaptation to TPM of the IPsec tools for Linux will be done. Finally a privacy enhancement of the SSL/TLS protocols will be defined and implemented and a study about the privacy enhancement the IKE/ISAKMP protocols will be done.

d) JAVA Integration
To support a broad range of existing applications, it is essential to integrate TCG/TPM-technology also in an application environment like Java. There are a lot of JAVA and network applications like grid computing, web services or mobile applications will highly benefit from TPM functionality.

2 D03b1: TSS-Stack according to TCG Specification. (IFX)

The TCG main specification defines a subsystem with protected storage and protected capabilities: This subsystem is the Trusted Platform Module (TPM). Since the TPM is both a subsystem intended to provide trust and be an inexpensive component, resources within it are restricted. This narrowing of the resources, while making the security properties easier and cheaper to build and verify, causes to the interfaces and capabilities to be cumbersome. The TCG architecture has solved this by separating the functions requiring the protected storage and capabilities from the functions that do not; putting those that do not into the platform’s main processor and memory space where processing power and storage exceed that of the TPM. The modules and components that provide this supporting functionality comprise the TSS.

Due to its special role, as the central trust API to the trusted hardware (TPM) it will be used as trust API for the operating system as well as for the applications. The TSS definition is publicly available at the TCGs website /1/.

The TCG Software Stack (the TSS) is the supporting software on the platform for connecting the platform’s TPM security processor. Its specification was done by the TCG and is publicly available at the internet at [TCG05]. Within the project we will adapt the TSS to the requirements of Linux OS.

2.1 TSS Architecture

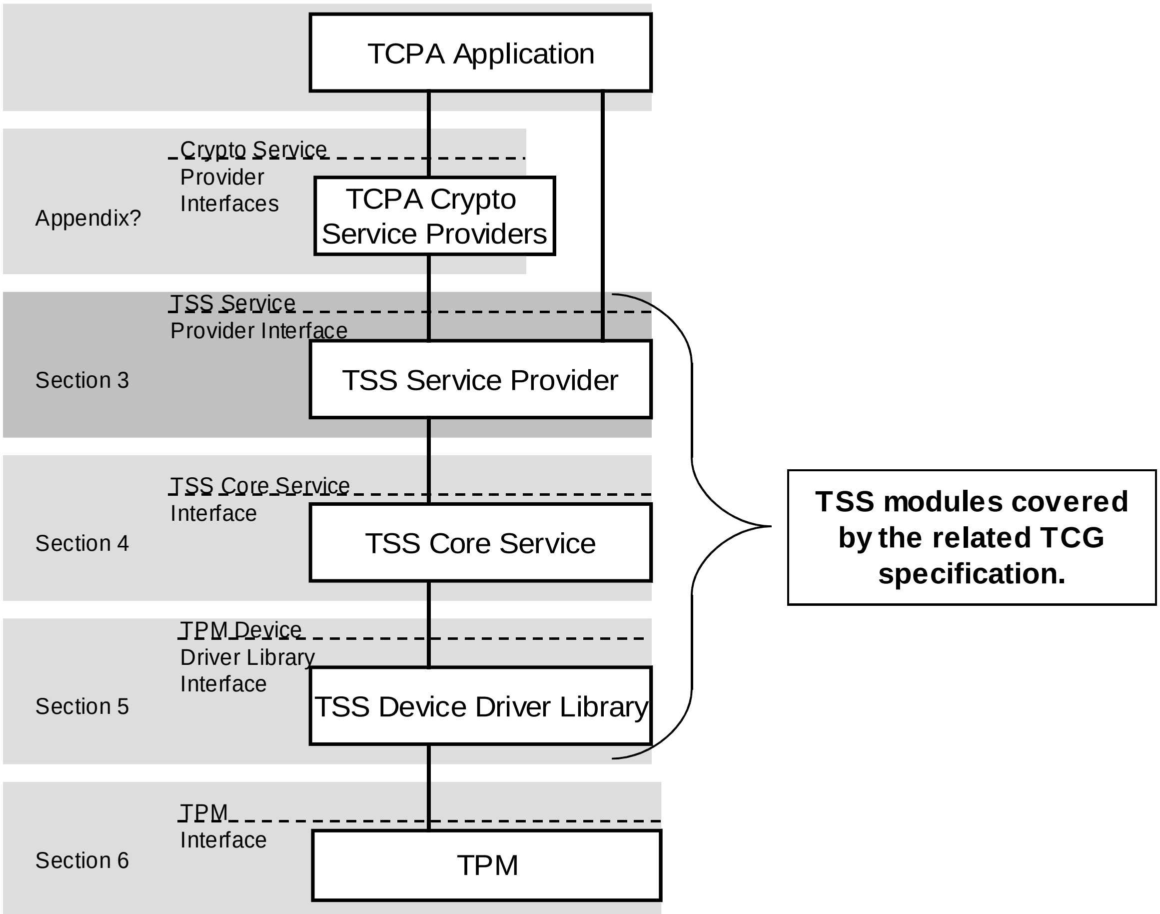


Figure 2: TSS-Stack

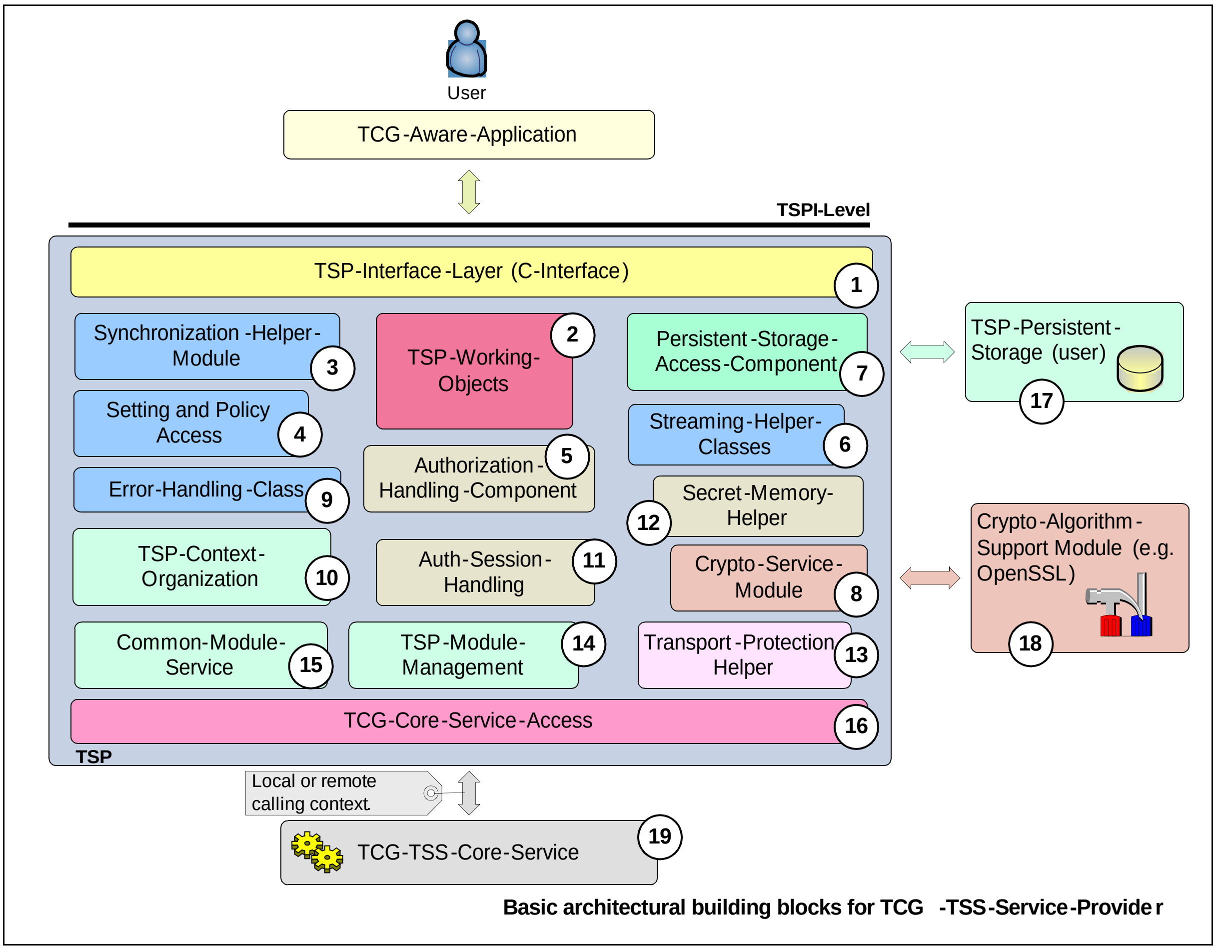
3 TSS module architectural overview

Differently to other TSS realizations, where a monolithic implementation is chosen, we selected a distributed, modular implementation. Every module has a selected functionality, which is also referenced by the structure of the TCG specification. Well defined interfaces will allow a thorough understanding of the whole structure esp. for any changes which will come up later. This is esp. advantageous for adapting this TSS to changes and extensions of the general specification which may come up later due to the forth going work of the TCG standardization groups. A continuous support for further development in this field will therefore be supported.

3.1 TCG-TSP architectural building blocks

This module provides TCG services for applications. It provides the high-level TCG functions allowing applications to focus on their specialty while relying on the TSP to perform most of the trusted functions provided by the TPM. This module also provides a small number of auxiliary functions for convenience not provided by the TPM such as hashing.

In environments that provide layers of protections (i.e., rings) or separation of applications into processes, this module is intended to reside within the same ring and process as the application. There will likely be one TSP per application. On operating systems that provide multiple processes, there may be multiple TSP’s residing on the platform.

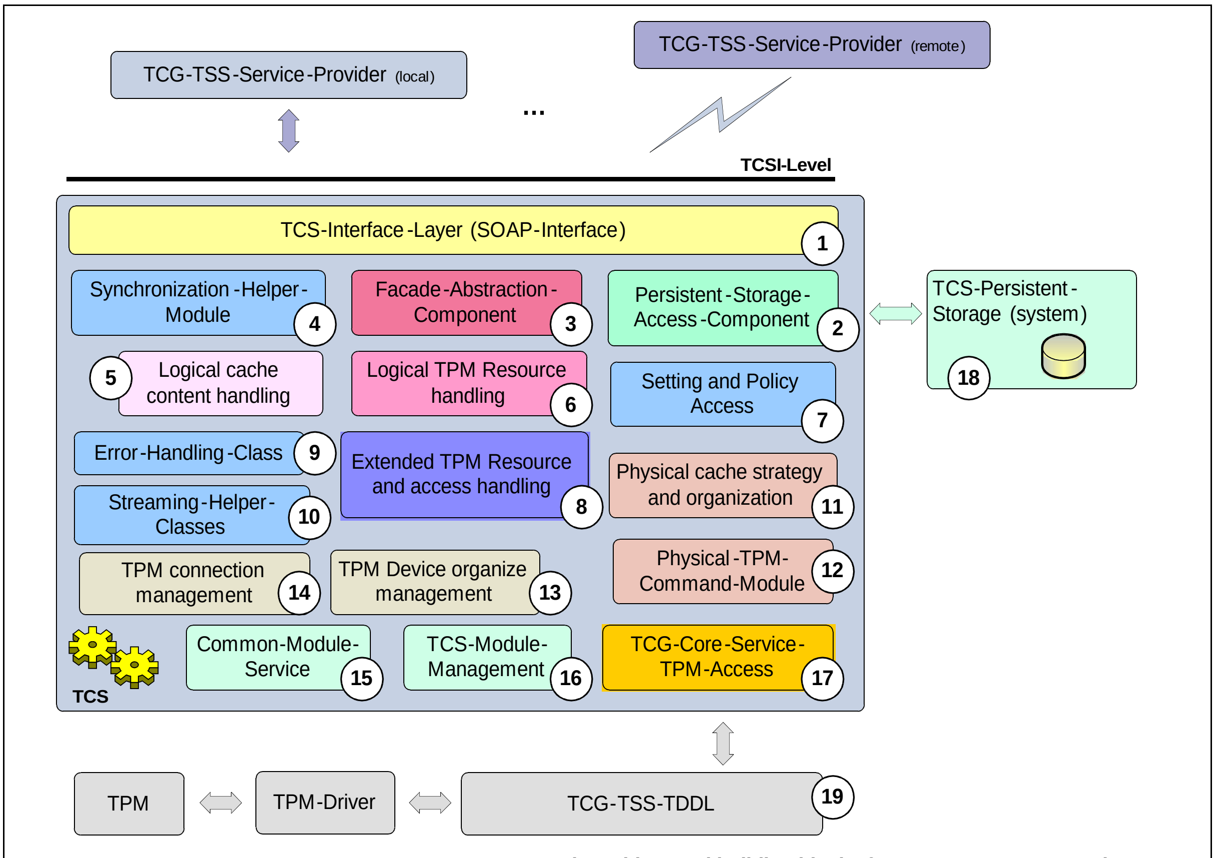


- **TSP-Interface-Layer (C-Interface)**
  Represents the TSPI of the TSS-Service-Provider and uses the C-Interface notation. Includes the first object access abstraction layer; accomplishing the object oriented nature of the TSP interface. Contains functionality to create and release interface layer objects which are linked to the working layer.
- **TSP-Working-Objects**
  Collection of all TSP related productive objects (e.g. Key, EncData…). Act as a kind of business workflow control for all TCG related transformations and calculations. These operations are performed with assistance of the different specialized support components and classes.
- **Synchronization-Helper-Module**
  Collection of some small helper classes; encapsulate the native system calls for synchronization object handling.
- **Setting and Policy Access**
  Function and class pool to summarize operations used to access and validate setting information.
- **Authorization-Handling-Component**
  Component contains the knowledge and TPM command parameter data for the authorization data stream construction. This unit interacts with the TSP-Policy-Class from the TSP-Working-Object and the Auth-Session-Handling module to calculate the authorization (e.g. HMAC) data package. It interacts as a kind of instrumentation factor for the TCG authorization flow.

- **Streaming-Helper-Classes**
  Helper classes transform TCG structures into BYTE-Stream-Representation and verse versa.
- **Persistent-Storage-Access-Component**
  Component covers the physical access and representation of the TSP persistent storage representation. The TSS specification separates the storage context into a per user boundary and in a system linked one. This functionality and the data representation reflect a TSS (i.e. TSP and TCG) common code component.
- **Crypto-Service-Module**
  Abstraction layer to offer a set of cryptographic functions needed for the TCG related data transformations (e.g. HMAC, SHA1...) in the TSP. The native algorithm suite is not part of the TSP module.
- **Error-Handling-Class**
  Helper class(es) used in the exception handling process of the TSS components (i.e. TSP and TCS). The structured exception concept will be used for error handling inside of the TSS modules.
- **TSP-Context-Organization**
  Cover the lifetime control for all TSP context object elements. Represent a kind of garbage collection for open context resources.
- **Auth-Session-Handling**
  Envelop the lifetime control for all TSP authorization sessions for a context object element. Contain functionality to validate the status of the sessions.
- **Secret-Memory-Helper**
  Offer functionality for limited permission memory area access used to store e.g. secret data.
- **Transport-Protection-Helper**
  Set of helper function to support the construction (e.g. encrypt, decrypt...) of the transport protection related data streams. In addition export the central execution method for transport protected communication.
- **TSP-Module-Management**
  General operations used to administrate and arrange TSP module wide services (e.g. memory handling).
- **Common-Module-Service**
  Common functions used for TSP module management (e.g. registration, load and unload).
- **TCG-Core-Service-Access**
  Component covers the physical access and representation of the TCS communication. Abstraction layer offer the functions to establish, operate and close the TCS communication in a local and a remote situation.
- **TSP-Persistent-Storage (User)**
  Contain the physical data representation for TSP persistent storage. The preferred mechanism would be XML based.
- **Crypto-Algorithm-Support-Module**
  Extern crypto module or library (e.g. OpenSSL) which offers all basic algorithms (e.g. hashing) required to derive the TSP crypto function set (e.g. HMAC).
- **TCG-TSS-Core-Service**
  System service reflects the TSS-Core-Service.

3.2 TCG-TCS architectural building blocks

A service provider is any component used by the application that allows that application access to the TCS (and thus the TPM) from within the application's process. Service providers, of which the TSP is but one possible instantiation, cannot communicate directly with the TPM. Additionally, there are multiple common services that either must or should be shared among the set of the platform's service providers.
The TCG Core Services (TCS) provides a common set of services per platform for all service providers. Since the TPM is not required to be multithreaded, it provides threaded access to the TPM. The TCS MUST provide single threaded access to the TPM and is an out of process system service.



Basic architectural building blocks for TCG -TSS-Core-Service

1. **TCS-Interface-Layer (SOAP-Interface)**
   The interface to the TCS is the TCS Interface (Tcsi). This is a simple 'C' style interface but should be realized in SOAP. While it may allow multithreaded access to the TCS, each operation is intended to be atomic. It resides as a system process, separate from the application and service provider processes. If the environment provides for the TCS to reside in a system process, communication between the service providers and the TCS would be via an RPC.
2. **Persistent-Storage-Access-Component (System)**
   Component covers the physical access and representation of the TCS persistent storage representation. The TSS specification separates the storage context into a per user boundary and in a system linked one. This functionality and the data representation reflect a TSS (i.e. TSP and TCG) common code component.
3. **Facade-Abstraction-Component**
   Component contains a facade factory to generate separate facade objects per calling context. This layer performs the parameter checking for the TCS-Interface.
4. **Synchronization-Helper-Module**
   Collection of some small helper classes; encapsulate the native system calls for synchronization object handling.
5. **Logical cache content handling**
   Characterize a logical TPM device per connection context and organize logical resource cache management.
6. **Logical TPM Resource handling**
   Contain a management class and resource classes for the two major handled resource types key and authorization sessions. The task is divided into a resource map management and into a resource representation unit.
7. **Setting and Policy access**
   Function and class pool to summarize operations used to access and validate setting information.
8. **Extended TPM Resource and access handling**
   Characterize a physical TPM device is designed as singleton and organize physical resource cache management. Due to the character as single entry point for all TPM operations this layer is responsible for TPM access synchronization.
9. **Error-Handling-Class**
   Helper class(es) used in the exception handling process of the TSS components (i.e. TSP and TCS). The structured exception concept will be used for error handling inside of the TSS modules.
10. **Streaming-Helper-Classes**
    Helper classes transform TCG structures into BYTE-Stream-Representation and verse versa.
11. **Physical cache strategy and organization**
    Contain a physical management classes and resource classes for the two major handled resource types key and authorization sessions. The task is divided into a resource map management and into a resource representation unit. In addition this component automatically detects the underlying TPM device version and selects the corresponding physical caching strategy and function set.
12. **Physical-TPM-Command-Module**

Module is responsible for the TPM command stream generation (byte-stream-generator) receiving the response and extracting the response parameter elements.

13. **TPM-Device organize management**
Component includes classes and functionality to handle TPM device specific startup and shutdown procedures. In addition it controls the consistence of the resource management of the TCS.
14. **TPM connection management**
Contain the management classes and functionality to establish the connection to the TPM device. A further task is to setup the power management control handling between IFX-TPM-Driver and TCS.
15. **Common-Module-Service**
Common functions used for TCS module management (e.g. registration, start and stop).
16. **TCS-Module-Management**
General operations used to administrate and arrange TCS module wide services (e.g. memory handling).
17. **TCG-Core-Service-TPM-Access**
Component covers the physical access and representation of the TDDL communication. Abstraction layer offer the functions to establish, operate and close the TPM communication in a local situation.
18. **TCS-Persistent-Storage (System)**
Contain the physical data representation for TCS persistent storage (on per system and access able for all users). The preferred mechanism would be XML based.

3.3 TDDL and TDDLI

The TCG Device Driver Library (TDDL) is an intermediate module that exists between the TCS and the kernel mode TPM Device Driver (TDD). The TDDL provides a user mode interface. Such an interface has several advantages over a kernel mode driver interface:

- It ensures different implementations of the TSS properly communicate with any TPM.
- It provides an OS-independent interface for TPM applications.
- It allows the TPM vendor to provide a software TPM simulator as a user mode component.

Because the TPM is not required to be multithreaded, the TDDL is to be a single-instance, single threaded module. The TDDL expects the TPM command serialization to be performed by the TCS.

The TPM vendor is responsible for defining the interface between the TDDL and the TDD. The TPM vendor can choose the communication and resource allocation mechanisms between this library and any kernel mode TPM device driver or software TPM simulator.

3.4 References

TCG TPM Specification Version 1.2

https://www.trustedcomputinggroup.org
Part1 Design Principles, Part2 Structures of the TPM, Part3 TPM Commands
September, 2005,
Revision 94

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February 22, 2002,
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/1/ TCG Software Stack (TSS) Specification v1.1 and v1.2

https://www.trustedcomputinggroup.org
October 8, 2002,
Version 1.0 RC 7 / Version TSS v1.2 GC 2 Errata 3c November, 2005

3.5 Definitions of terms, Acronyms and abbreviations

Listing of term definitions and abbreviations which are important for understanding the overview documents and architectural design specification (IT expressions and terms from the application domain) .

Abbreviation	Explanation
API	Application Programming Interface
ODBC	Open Database Connectivity
PC	Personal Computer
SDK	Software Development Kit
SW	Software
TSP	TCG Service Provider
TSPI	TSP-Interface
TCS	TCG Core Service
TCSI	TCG-Interface
TDDL	TCG-Device Driver Library
TDDLI	TDDL-Interface
TPM	Trusted Platform Module
TSS	TCG-Software-Stack
TSS-SDK	TSS-Software-Development-Kit
GUID	Globally Unique Identifier (a 128-bit value)
XML	Extensible Markup Language
BUK	Basic User Key
TCG	Trusted Computing Group
SOAP	Simple Object Access Protocol
HTTP	Hypertext Transfer Protocol

D03b.1 TPM Software Stack (TSS) Implementation and Test Report

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Report (see p 84/85 Annex 1 - Nature)

Deliverable reference number	IST-027635/D3.1/RC 1.0
Deliverable title	TPM Software Stack (TSS) Implementation and Test Report
WP contributing to the deliverable	WP3
Due date	JUL2007

Responsible Organisation	IFX
Authors	IFX (Hans Brandl)
Abstract	The main specification of the TCG defines a subsystem with protected storage and trust capabilities: The Trusted Platform Module (TPM). For translating the low level functionality fo the TPM security chip to a high level API, the TCG standardized the so called TPM Software Stack (TSS). Within this deliverable a TSS was implemented according of the TSS1.2 specification of the TCG. This report describes the method of implementation and also the test procedures during the development process as well as a third party test of the finished product.
Keywords	TPM, TSS, TSPI, TCG, Trust, Security, Tes

Dissemination level	Public
Revision	RC 1.0

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

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1 Introduction

The main specification of the TCG defines a subsystem with protected storage and trust capabilities: This subsystem is the Trusted Platform Module (TPM). Since the TPM is both a subsystem intended to provide trust and be an inexpensive component, resources within it are restricted. This narrowing of the resources, while making the security properties easier and cheaper to build and verify, causes to the interfaces and capabilities to be cumbersome. The TCG architecture has solved this by separating the functions requiring the protected storage and capabilities from the functions that do not; putting those that do not into the platform's main processor and memory space where processing power and storage exceed that of the TPM. The modules and components that provide this supporting functionality comprise the TPM Software Stack (TSS) .

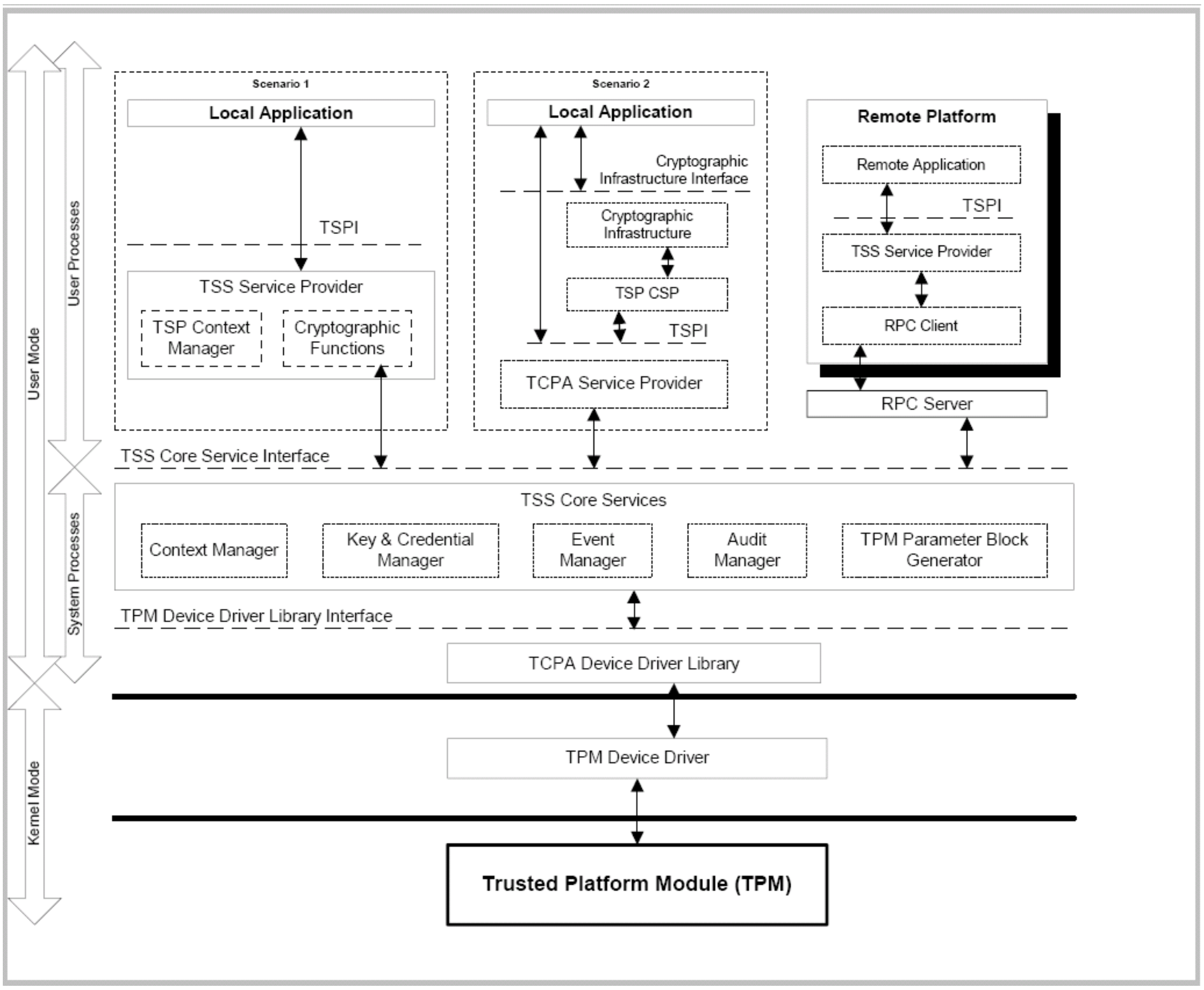

Figure 1: TSS-Stack as defined by the TCG

Due to its special role, as the central trust API to the trusted hardware (TPM) it will be used as trust API for the operating system as well as for the applications.

The TSS definition is publicly available at the TCGs website as newest version 1.2 www.trustedcomputing.org . The old and first version of this stack V1.0 has been already implemented by IFX for Windows machines in year 2003. As since this first implementation a lot of new findings and experiences for the TSS came up, the TCG TSS work group created the current follow on version1.2 of the standard in the periode of year 2005 to 2006.

Within this project an intensive cooperation with the TCG TSS WG was executed and in parallel to the work on the TCG standard also this implementation was done. There where a lot of benefits for the standardisation work group, because the implementation results where immediately fed back and on the other hand this implementation became the newest and most up to date one which is currently available (The 1.2 standard is now public since march 2007 and nearly at the same time the first beta prototype of this TSS was ready) .

For implementation efficiency we tried to use as much as possible code from the old Windows version. However some of the functions had to be programmed fully new, because of the different interfacing to Win and Linux (especially low level kernel functions) and nearly all code had to be modified either due to the conversion to Linux but also because of major changes in the standard from version 1.0 to 1.2.

The TSS1.2 specification, which was considered, has a volume of 757 pages.

The final amount of code for this TSS1.2 implementation reached about 95 KLoc.

For testing purposes we added another 25 KLoc of example programs , which use the stack features.

The complete packetsize of the current TSS implementation is about 4 Mbytes.

The implementation was done on Linux distribution SUSE 10.0 to 10.2 as this is the standard Linux version for the OpenTC project.

The whole package is available at the OpenTC server and can be downloaded and compiled at the users target machine. All necessary command and control files (MAKE) are enclosed to allow an easy integration.

As we found out in contact with potential users, that a local compilation could rise problems for not much experienced users, we also added precompiled binary versions which could much more easily installed.

1.1 TPM Management Interface

For managing and controlling the TPM (below the TSS) within WP5 a specific TPM Control package has been specified and developed . With the functionality from this package all main TPM management operations can be executed and the status of the TPM can be analyzed. The functionality is basically described in chapter 11, the detailed description and code can be found in the results from WP5d and the respective delivery. It is described here shortly because it has been developed together with this TSS and can be used for doing some early tests and starting getting experience with handling the TPM.

1.2 Description of work:

- The TSS stack has been developed with all mandatory functions acording to the TCG TSS specifications and is now worldwide the first 1.2 version ready for use. There are certain functions, which are not required for practical use or which are still in discussion. For sake of clarity we have in accordance with TCG good practice not implemented these features until final settling of standardisation work will occur.
- A specific Linux based testbed and testprograms have been developed and the stack has been tested by this environment.
- The complete package (including source code, make files, environment infrastructure etc.) is available at the OpenTC svn server for use and feedback by the project partners.

1.2.1 Development of a test environment for the TSS stack

<u>Motivation and execution</u>

For a full coverage of the functionality and behaviour tests of the Linux TSS stack within the OpenTC project, we used two different test methods during development and implementations.

In addition to the PHP based test interface , which has advantages for manual testing and fast generation of result reports, we used also the well known RUBY environment for testing.

Small and compact code sequences are generated in the target programming language C as well as for the test environment based on the RUBY script language which use only small and compact functional of the TSS service provider. With such high granularity tests we will minimize the risk to ignore errors within the execution protocols. From the point of the Service provider (SP) both methods look nearly identical, because the complementary test process is either an executable program or an shared object from the universal test environment.

This run time library is following certain stringent rules, for allowing the RUBY interpreter to feed through and converting the script calls of the ruby interpreter.

Amongst the many available script languages for Linux, Ruby has been selected, because this language is consequently object oriented , the scripts are easily to read and the generation of a linkage library to connect to the TSS SP is very much supported by automatic code generation means.

Formal Requirements for the Test Scripts

To achieve a certain homogeneousness of the test scripts independent on the developer and to allow for an automated checking of the test results, the following rules shall be followed.

The name of a test script include the unique identifier of the test case it implements. It shall be obvious from the script’s name, which test case it realizes.

Each standalone script releases all variables by means of a instruction before terminating so that various standalone scripts can be invoked by means of include instructions by a master script.

Guidelines for Test Development

- Identify a test subject
- Insert a sub chapter into chapter TSPI of this document
- Write a short description of the test subject
- Develop the test scripts according to the table in the test plan. Usually, one test script will contain one test case.
- Fault test cases usually contain more than one test case in each row and each test script.
- Debug the test scripts with the help of the Scripting Debug Tool.

1.3 SW-design Fundamentals

1.3.1 References

TCG TPM Specification Version 1.2 Revision 103

https://www.trustedcomputinggroup.org
Specification Version 1.2
Level 2 Revision 103, 9 July 2007

TCG Specification Architecture Overview

https://www.trustedcomputinggroup.org
Specification Revision 1.3, 28th March 2007

TCG Software Stack (TSS)

https://www.trustedcomputinggroup.org
Specification Version 1.2, Level 1, Errata A, Part1: Commands and Structures, March 7, 2007

1.3.2 Definitions of terms, Acronyms and abbreviations

Listing of term definitions and abbreviations which are important for understanding the architectural design specification (IT expressions and terms from the application domain) - irrespective of whether these have already been explained in a different document (e.g. software requirements specification).

Abbreviation	Explanation
ACRYL	Advanced Cryptographic Library
API	Application Programming Interface
ODBC	Open Database Connectivity
PC	Personal Computer
SDK	Software Development Kit
SW	Software
TSP	TCG Service Provider
TSPI	TSP-Interface
TCS	TCG Core Service
TCSI	TCG-Interface
TDDL	TCG-Device Driver Library
TDDLI	TDDL-Interface
TPM	Trusted Platform Module
TSS	TCG-Software-Stack
TSS-SDK	TSS-Software-Development-Kit
GUID	Globally Unique Identifier (a 128-bit value)
XML	Extensible Markup Language
DOM	Document Object Model
COM	Component Object Mode
DCOM	Distributed Component Object Mode
IDL	Interface Definition Language
MIDL	Microsoft® Interface Definition Language
BUK	Basic User Key
TCG	Trusted Computing Group
SOAP	Simple Object Access Protocol
HTTP	Hypertext Transfer Protocol

Table 1: List of abbreviations and terms used for specification and definition

2 TSS Architecture

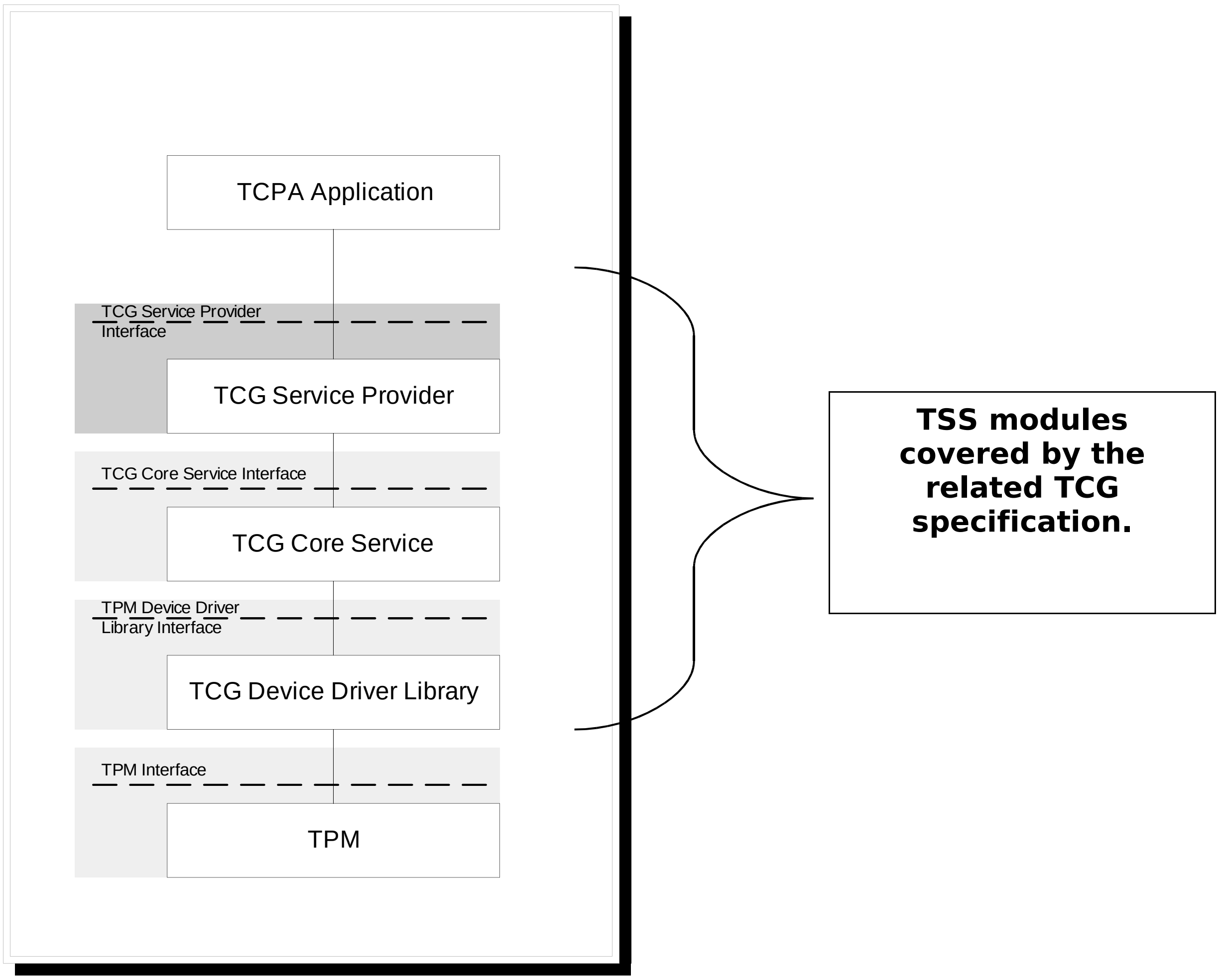

Figure 2:TPM Software Stack Structure

IFX-TSS modules considerations and inspection

2.1 TSP and TSPI

This module provides TCG services for applications. It provides the high-level TCG functions allowing applications to focus on their specialty while relying on the TSP to perform most of the trusted functions provided by the TPM. This module also provides a small number of auxiliary functions for convenience not provided by the TPM such as hashing.
In environments that provide layers of protections (i.e., rings) or separation of applications into processes, this module is intended to reside within the same ring and

process as the application. There will likely be one TSP per application. On operating systems that provide multiple processes, there may be multiple TSP's residing on the platform.

2.2 TCS and TCSI

A service provider is any component used by the application that allows that application access to the TCS (and thus the TPM) from within the application's process. Service providers, of which the TSP is but one possible instantiation, cannot communicate directly with the TPM. Additionally, there are multiple common services that either must or should be shared among the set of the platform's service providers.
The TCG Core Services (TCS) provides a common set of services per platform for all service providers. Since the TPM is not required to be multithreaded, it provides threaded access to the TPM. The TCS MUST provide single threaded access to the TPM and is an out of process system service.

2.3 TDDL and TDDLI

The TCG Device Driver Library (TDDL) is an intermediate module that exists between the TCS and the kernel mode TPM Device Driver (TDD). The TDDL provides a user mode interface. Such an interface has several advantages over a kernel mode driver interface:

- It ensures different implementations of the TSS properly communicate with any TPM.
- It provides an OS-independent interface for TPM applications.
- It allows the TPM vendor to provide a software TPM simulator as a user mode component.

Because the TPM is not required to be multithreaded, the TDDL is to be a single-instance, single threaded module. The TDDL expects the TPM command serialization to be performed by the TCS.
The TPM vendor is responsible for defining the interface between the TDDL and the TDD. The TPM vendor can choose the communication and resource allocation mechanisms between this library and any kernel mode TPM device driver or software TPM simulator.
This module will be totally removed from the Infineon Technologies TSS package if it is part of the OS distribution (e.g. Linux) for OpenTC. In the meantime we will implement the basic functionality for this module to interact with the TPM device.

2.4 Maintainability, Portability and Usability Requirements

- The Security Platform requires the Infineon TPM SLB9635TT1.2 be setup properly with the TPM 1.2 firmware V1.00 or higher.

Generally Infineon provides a firmware update possibility via a tool based on the TCPA field upgrade approach which will be deployed by means comparable to driver updates.

3 TCG-API

3.1 Function list for the OpenTC TCG-TSS

3.1.1 List of supported TSS Core Service Interface Functions

TSS Core Service Function as specified by TCG	Solution-Supported	Not Supported
Context related		
Core Service functionality covered by DCOM	X	
TCS_OpenContext	(x)	
TCS_CloseContext	(x)	
TCS_FreeMemory	(x)	
TCS_GetCapability	0	
Persistent Storage related		
TCSP_LoadKeyByUUID	O	
TCS_RegisterKey	X	
TCSP_UnregisterKey	X	
TCS_EnumRegisteredKeys		X
TCS_GetRegisteredKey	O	
TCS_GetRegisteredKeyBlob	X	
TCSP_GetRegisteredKeyByPublicInfo		X
Authorization related		
TCSP_OIAP	X	
TCSP_OSAP	X	
TCSP_TerminateHandle	X	
TCSP_ChangeAuth	X	
TCSP_ChangeAuthOwner	X	
TCSP_ChangeAuthAsymStart		X
TCSP_ChangeAuthAsymFinish		X
TPM related		
TCSP_CreateEndorsementKey		X
TCSP_ReadPubek	X	
TCSP_OwnerReadPubek	X	
TCSP_OwnerReadInternalPub	X	
TCSP_TakeOwnership	X	
TCSP_OwnerClear	X	
TCSP_ForceClear	X	
TCSP_DisableOwnerClear	X	
TCSP_DisableForceClear	X	
TCSP_OwnerSetDisable	X	
TCSP_PhysicalDisable	X	
TCSP_PhysicalEnable	X	

TSS Core Service Function as specified by TCG	Solution-Supported	Not Supported
TCSP_PhysicalSetDeactivated	X	
TCSP_SetTempDeactivated	X	
TCSP_SetOwnerInstall	X	
TCSP_DisablePubekRead	X	
TCSP_GetCapabilityOwner	X	
TCSP_SelfTestFull	X	
TCSP_CertifySelfTest		X
TCSP_GetTestResult	X	
TCSP_GetCapability	X	
TCSP_GetCapabilitySigned		
TCSP_CreateMaintenanceArchive		X(1)
TCSP_LoadMaintenanceArchive		X(1)
TCSP_KillMaintenanceFeature		X(1)
TCSP_LoadManuMaintPub		X(1)
TCSP_ReadManuMaintPub		X(1)
TCSP_FieldUpgrade	X	
TCSP_SetRedirection		X(1)
TCSP_GetRandom	X	
TCSP_StirRandom	X	
TCSP_Quote	X	
TCSP_Extend	X	
TCSP_PcrRead	X	
TCSP_DirWriteAuth	X	
TCSP_DirRead	X	
TCSP_SetCapability	O	
TCSP_FlushSpecific	X	
TCSP_ResetLockValue	X	
TCSP_OwnerReadInternalPub		X
TCSP_KeyControlOwner		X
TCSP_CreateRevocableEndorsementKeyPair		X
TCSP_RevokeEndorsementKeyPair		X
PCREvent related		
TCS_GetPcrEvent		X
TCS_GetPcrEventsByPcr		X
TCS_GetPcrEventLog		X
TCS_LogPcrEvent		X
Key related		
TCSP_EvictKey	X	
TCSP_LoadKeyByBlob	X	
TCSP_GetPubkey	X	
TCSP_CertifyKey	X	
TCSP_CreateWrapKey	X	
TCSP_LoadKey2ByBlob	X	
TCSP_MigrateKey		X
AIK related		
TCSP_MakeIdentity	X	

TSS Core Service Function as specified by TCG	Solution-Supported	Not Supported
TCSP_ActivateIdentity	X	
Migration related		
TCSP_AuthorizeMigrationKey	X	
TCSP_CreateMigrationBlob	X	
TCSP_ConvertMigrationBlob	X	
Hash related		
TCSP_Sign	X	
Data related		
TCSP_Unbind	X	
TCSP_Seal	X	
TCSP_Unseal	X	
NV related		
Tcsip_NV_DefineOrReleaseSpace	X	
Tcsip_NV_WriteValue	X	
Tcsip_NV_WriteValueAuth	X	
Tcsip_NV_ReadValue	X	
Tcsip_NV_ReadValueAuth	X	

O The implementation doesn't support all possible parameter features as described by TCG
(X) This function is implicitly supported through the COM interface technology
X(1) Optional TPM commands according to TCG Main Specification
X(2) The support of these commands has a high priority for the next release

Table 2: TSS Core Service Function as specified by TCG

3.2 Function list for the OpenTC TCG-TSS

For the OpenTC development/porting of the Infineon TCG-TSS the intention is to separate this into some iteration step. Iterations should be organized that it is possibility to offer a delivery to the OpenTC project as early as possible.
Currently the functionality for DAA and CMK are not included in the development plan; due to the fact that there is no use case in the OpenTC project which addresses these functions and also use scenarios outside the OpenTC are not known.

3.2.1 Supported function list of TSS Service Provider

TSS Service Provider Function as specified by TCG	Step-1 Supported	Step-2 Supported
Context related		
Service Provider functionality covered by (D)COM		
Tspi_Context_Create	X	
Tspi_Context_Close	X	
Tspi_Context_FreeMemory	X	
Tspi_SetAttribUint32	O	O
Tspi_GetAttribUint32	O	O
Tspi_SetAttribData		
Tspi_GetAttribData		
Tspi_Context_Connect	X	
Tspi_Context_GetDefaultPolicy	X	
Tspi_Context_CreateObject	O	O
Tspi_Context_CloseObject	X	
Tspi_Context_GetCapability	O	O
Tspi_Context_GetTPMObject	X	
Tspi_Context_LoadKeyByBlob	X	
Tspi_Context_LoadKeyByUUID	O	O
Tspi_Context_RegisterKey		O
Tspi_Context_UnregisterKey		O
Tspi_Context_DeleteKeyByUUID		
Tspi_Context_GetKeyByUUID		O
Tspi_Context_GetKeyByPublicInfo		
Tspi_Context_GetRegisteredKeysByUUID		
Policy related		
Tspi_SetAttribUint32		
Tspi_GetAttribUint32		
Tspi_SetAttribData		
Tspi_GetAttribData		
Tspi_Policy_SetSecret	O	

TSS Service Provider Function as specified by TCG	Step-1 Supported	Step-2 Supported
Tspi_Policy_FlushSecret	X	
Tspi_Policy_AssignToObject	X	
TPM related		
Tspi_SetAttribUint32	O	O
Tspi_GetAttribUint32	O	O
Tspi_SetAttribData	O	O
Tspi_GetAttribData	O	O
Tspi_TPM_CreateEndorsementKey		
Tspi_TPM_GetPubEndorsementKey		
Tspi_TPM_TakeOwnership	X	
Tspi_TPM_CollateIdentityRequest		O
Tspi_TPM_ActivateIdentity		O
Tspi_TPM_ClearOwner	X	
Tspi_TPM_SetStatus	O	
Tspi_TPM_GetStatus	O	
Tspi_TPM_SelfTestFull		
Tspi_TPM_CertifySelfTest		O
Tspi_TPM_GetTestResult	X	
Tspi_TPM_GetCapability	O	
Tspi_TPM_GetCapabilitySigned		
Tspi_TPM_CreateMaintenanceArchive		
Tspi_TPM_LoadMaintenanceArchive		
Tspi_TPM_KillMaintenanceFeature		
Tspi_TPM_LoadMaintenancePubKey		
Tspi_TPM_CheckMaintenancePubKey		
Tspi_TPM_SetRedirection		
Tspi_TPM_GetRandom	X	
Tspi_TPM_StirRandom		X
Tspi_TPM_AuthorizeMigrationTicket		
Tspi_TPM_GetEvent		
Tspi_TPM_GetEvents		
Tspi_TPM_GetEventLog		
Tspi_TPM_Quote		O
Tspi_TPM_PcrExtend	O	O
Tspi_TPM_PcrRead	X	X
Tspi_TPM_DirWrite		
Tspi_TPM_DirRead		
Tspi_ChangeAuth	X	
Tspi_GetPolicyObject	X	
Key related		
Tspi_SetAttribUint32	O	O
Tspi_GetAttribUint32	O	O
Tspi_SetAttribData	O	O
Tspi_GetAttribData	O	O
Tspi_Key_LoadKey	X	
Tspi_Key_GetPubKey	X	
Tspi_Key_CertifyKey		X

TSS Service Provider Function as specified by TCG	Step-1 Supported	Step-2 Supported
Tspi_Key_CreateKey	O	O
Tspi_Key_WrapKey		
Tspi_Key_CreateMigrationBlob		O
Tspi_Key_ConvertMigrationBlob		O
Tspi_ChangeAuth	X	
Tspi_ChangeAuthAsym		
Tspi_GetPolicyObject	X	
Hash related		
Tspi_Hash_Sign	X	
Tspi_Hash_VerifySignature	O	
Tspi_Hash_SetHashValue	O	
Tspi_Hash_GetHashValue	O	
Tspi_Hash_UpdateHashValue		
Data related		
Tspi_SetAttribUint32		
Tspi_GetAttribUint32		
Tspi_SetAttribData	O	
Tspi_GetAttribData	O	
Tspi_Data_Bind		
Tspi_Data_Unbind		
Tspi_Data_Seal	X	
Tspi_Data_Unseal	X	
Tspi_ChangeAuth	X	
Tspi_ChangeAuthAsym		
Tspi_GetPolicyObject	X	
NV related		
Tspi_SetAttribUint32		O
Tspi_GetAttribUint32		O
Tspi_SetAttribData		
Tspi_GetAttribData		O
Tspi_NV_DefineSpace		
Tspi_NV_ReleaseSpace		
Tspi_NV_WriteValue		X
Tspi_NV_ReadValue		
PcrComposite related		
Tspi_PcrComposite_SelectPcrIndex		X
Tspi_PcrComosite_SetPcrValue		X
Tspi_PcrComposite_GetPcrValue		X
Callback Function Definitions		
Tspip_CallbackHMACAuth		
Tspip_CallbackXorEnc		X
Tspip_CallbackTakeOwnership		
Tspip_CallbackChangeAuthAsym		

O The implementation doesn’t support all possible parameter features as described by TCG

Table 3: TSS Service Provider Function as specified by TCG

3.2.2 List of supported TSS Core Service Interface Functions

TSS Core Service Function as specified by TCG	Step-1 Supported	Step-2 Supported
Context related		
Core Service functionality covered by DCOM		
TCS_OpenContext	X	
TCS_CloseContext	X	
TCS_FreeMemory	X	
TCS_GetCapability	O	O
Persistent Storage related		
TCSP_LoadKeyByUUID		O
TCS_RegisterKey		O
TCSP_UnregisterKey		O
TCS_EnumRegisteredKeys		
TCS_GetRegisteredKey		O
TCS_GetRegisteredKeyBlob		O
TCSP_GetRegisteredKeyByPublicInfo		
Authorization related		
TCSP_OIAP	X	
TCSP_OSAP	X	
TCSP_TerminateHandle	X	
TCSP_ChangeAuth	X	
TCSP_ChangeAuthOwner	X	
TCSP_ChangeAuthAsymStart		
TCSP_ChangeAuthAsymFinish		
TPM related		
TCSP_CreateEndorsementKey		
TCSP_ReadPubek	X	
TCSP_OwnerReadPubek	X	
TCSP_OwnerReadInternalPub	X	
TCSP_TakeOwnership	X	
TCSP_OwnerClear	X	
TCSP_ForceClear	X	
TCSP_DisableOwnerClear		
TCSP_DisableForceClear		
TCSP_OwnerSetDisable		
TCSP_PhysicalDisable	X	
TCSP_PhysicalEnable	X	
TCSP_PhysicalSetDeactivated	X	X
TCSP_SetTempDeactivated		X
TCSP_SetOwnerInstall	X	
TCSP_DisablePubekRead		
TCSP_GetCapabilityOwner		
TCSP_SelfTestFull		X

TSS Core Service Function as specified by TCG	Step-1 Supported	Step-2 Supported
TCSP_CertifySelfTest		
TCSP_GetTestResult		
TCSP_GetCapability	O	O
TCSP_GetCapabilitySigned		
TCSP_CreateMaintenanceArchive		
TCSP_LoadMaintenanceArchive		
TCSP_KillMaintenanceFeature		
TCSP_LoadManuMaintPub		
TCSP_ReadManuMaintPub		
TCSP_FieldUpgrade		X
TCSP_SetRedirection		
TCSP_GetRandom	X	
TCSP_StirRandom		
TCSP_Quote	X	
TCSP_Extend	X	
TCSP_PcrRead	X	
TCSP_DirWriteAuth		
TCSP_DirRead		
TCSP_SetCapability		O
TCSP_FlushSpecific	X	
TCSP_ResetLockValue		
TCSP_OwnerReadInternalPub		X
TCSP_KeyControlOwner		
TCSP_CreateRevocableEndorsementKeyPair		
TCSP_RevokeEndorsementKeyPair		
PCREvent related		
TCS_GetPcrEvent		
TCS_GetPcrEventsByPcr		
TCS_GetPcrEventLog		
TCS_LogPcrEvent		
Key related		
TCSP_EvictKey	X	
TCSP_LoadKeyByBlob	X	
TCSP_GetPubkey	X	
TCSP_CertifyKey		
TCSP_CreateWrapKey	X	
TCSP_LoadKey2ByBlob		
TCSP_MigrateKey		
AIK related		
TCSP_MakeIdentity		X
TCSP_ActivateIdentity		X
Migration related		
TCSP_AuthorizeMigrationKey		
TCSP_CreateMigrationBlob		
TCSP_ConvertMigrationBlob		
Hash related		

TSS Core Service Function as specified by TCG	**Step-1 Supported**	**Step-2 Supporte d**
TCSP_Sign	X	
Data related		
TCSP_Unbind		X
TCSP_Seal	X	
TCSP_Unseal	X	
NV related		
Tcsip_NV_DefineOrReleaseSpace		
Tcsip_NV_WriteValue		
Tcsip_NV_WriteValueAuth		
Tcsip_NV_ReadValue		
Tcsip_NV_ReadValueAuth		

O The implementation doesn’t support all possible parameter features as described by TCG

Table 4: TSS Core Service Function as specified by TCG

4 TSS module architectural overview

4.1 TCG-TSP architectural building blocks

This module provides TCG services for applications. It delivers the high-level TCG functions allowing applications to focus on their specialty while relying on the TSP to perform most of the trusted functions provided by the TPM. This module also provides a small number of auxiliary functions for convenience not provided by the TPM such as signature verification.
In environments that provide layers of protections (i.e., rings) or separation of applications into processes, this module is intended to reside within the same ring and process as the application. There will likely be one TSP per application. On operating systems that provide multiple processes, there may be multiple instances of TSP's running on the platform.

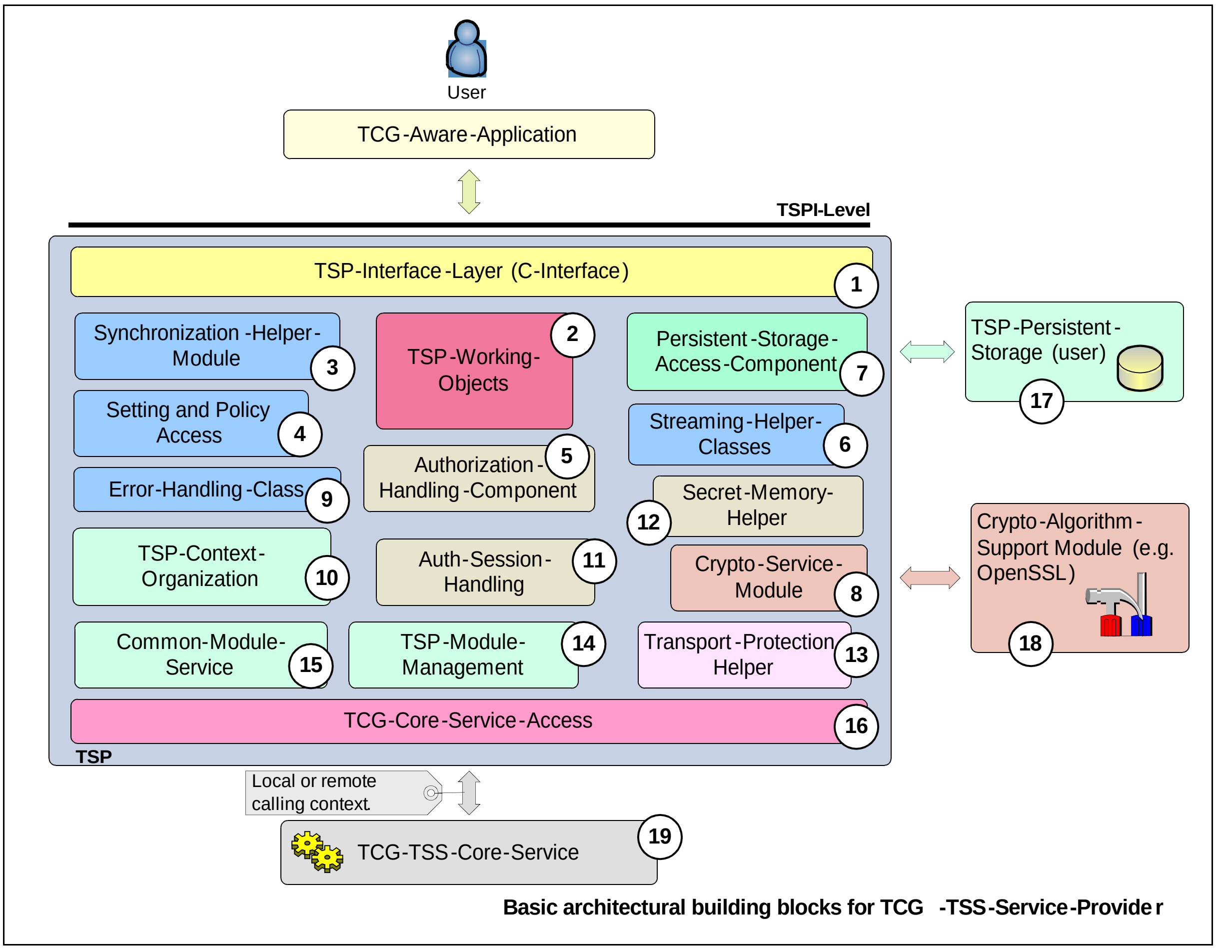

Figure 3: Basic architecture building blocks for TCG TSS Service-provider

1. **TSP-Interface-Layer (C-Interface)**
   Represents the TSPI of the TSS-Service-Provider and uses the C-Interface notation. Includes the first object access abstraction layer; accomplishing the object oriented nature of the TSP interface. Contains functionality to create and release interface layer objects which are linked to the working layer.
2. **TSP-Working-Objects**
   Collection of all TSP related productive objects (e.g. Key, EncData…). Act as a kind of business workflow control for all TCG related transformations and calculations. These operations are performed with assistance of the different specialized support components and classes.
3. **Synchronization-Helper-Module**
   Collection of some small helper classes; encapsulate the native system calls for synchronization object handling.
4. **Setting and Policy Access**
   Function and class pool to summarize operations used to access and validate setting information.
5. **Authorization-Handling-Component**
   Component contains the knowledge and TPM command parameter data for the authorization data stream construction. This unit interacts with the TSP-Policy-Class from the TSP-Working-Object and the Auth-Session-Handling module to calculate the authorization (e.g. HMAC) data package. It interacts as a kind of instrumentation factor for the TCG authorization flow.
6. **Streaming-Helper-Classes**
   Helper classes transform TCG structures into BYTE-Stream-Representation and verse versa.
7. **Persistent-Storage-Access-Component**
   Component covers the physical access and representation of the TSP persistent storage representation. The TSS specification separates the storage context into a per user boundary and in a system linked one. This functionality and the data representation reflect a TSS (i.e. TSP and TCG) common code component.
8. **Crypto-Service-Module**
   Abstraction layer to offer a set of cryptographic functions needed for the TCG related data transformations (e.g. HMAC, SHA1…) in the TSP. The native algorithm suite is not part of the TSP module.
9. **Error-Handling-Class**
   Helper class(es) used in the exception handling process of the TSS components (i.e. TSP and TCS). The structured exception concept will be used for error handling inside of the TSS modules.
10. **TSP-Context-Organization**
    Cover the lifetime control for all TSP context object elements. Represent a kind of garbage collection for open context resources.
11. **Auth-Session-Handling**
    Envelop the lifetime control for all TSP authorization sessions for a context object element. Contain functionality to validate the status of the sessions.
12. **Secret-Memory-Helper**
    Offer functionality for limited permission memory area access used to store e.g. secret data.
13. **Transport-Protection-Helper**
    Set of helper function to support the construction (e.g. encrypt, decrypt…) of the transport protection related data streams. In addition export the central execution method for transport protected communication.

14. **TSP-Module-Management**
    General operations used to administrate and arrange TSP module wide services (e.g. memory handling).
15. **Common-Module-Service**
    Common functions used for TSP module management (e.g. registration, load and unload).
16. **TCG-Core-Service-Access**
    Component covers the physical access and representation of the TCS communication. Abstraction layer offer the functions to establish, operate and close the TCS communication in a local and a remote situation.
17. **TSP-Persistent-Storage (User)**
    Contain the physical data representation for TSP persistent storage. The preferred mechanism would be XML based.
18. **Crypto-Algorithm-Support-Module**
    Extern crypto module or library (e.g. OpenSSL) which offers all basic algorithms (e.g. hashing) required to derive the TSP crypto function set (e.g. HMAC).
19. **TCG-TSS-Core-Service**
    System service reflects the TSS-Core-Service.

4.2 TCG-TCS architectural building blocks

A service provider is any component used by the application that allows that application access to the TCS (and thus the TPM) from within the application's process. Service providers, of which the TSP is but one possible instantiation, cannot communicate directly with the TPM. Additionally, there are multiple common services that either are either required to be shared or should be shared among the set of the platform's service providers.
The TCG Core Services (TCS) provides a common set of services per platform for all service providers. Since the TPM is not required to be multi-threaded, it provides threaded access to the TPM.

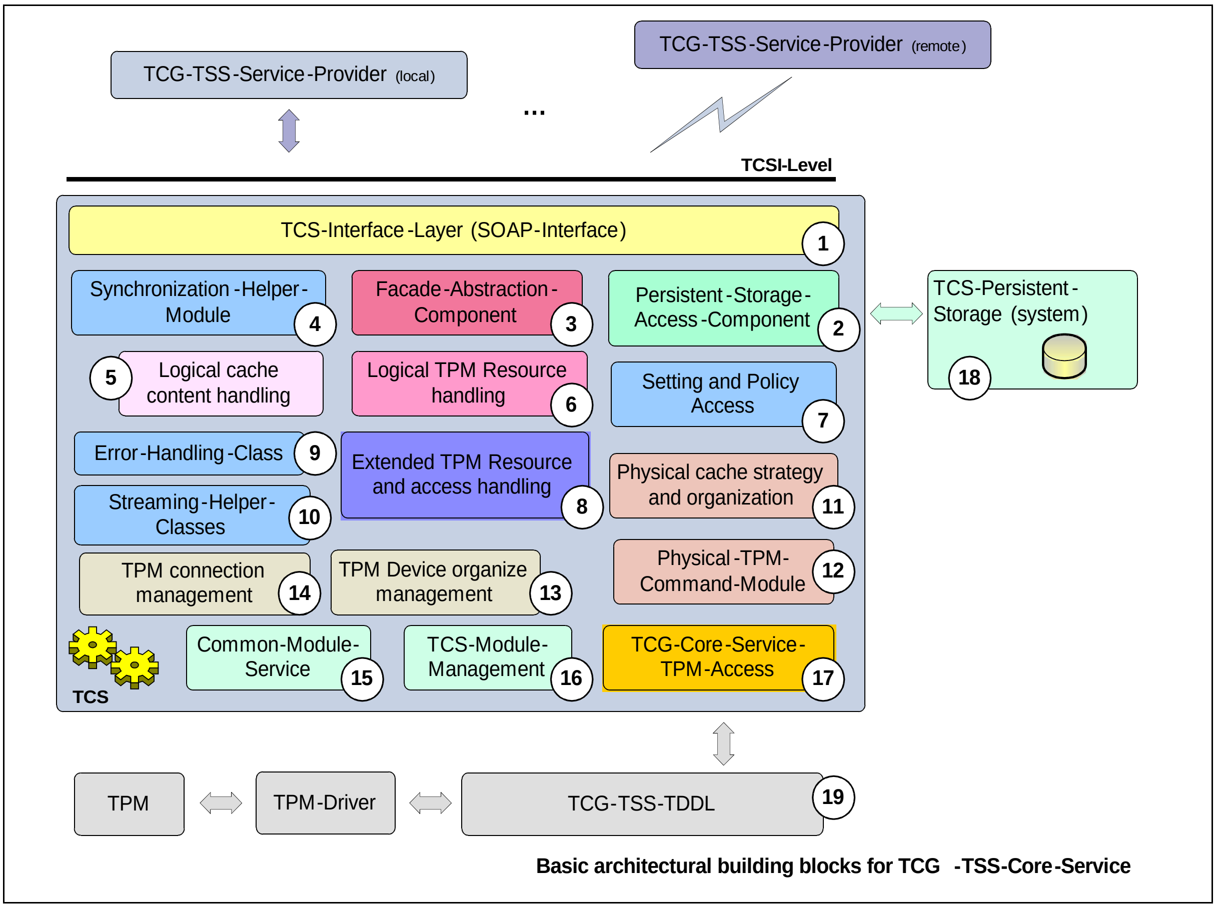

Figure 4: Basic architecture building blocks for TCG TSS CORE Service

1. **TCS-Interface-Layer (SOAP-Interface)**
   The interface to the TCS is the TCS Interface (Tcsi). This is a simple 'C' style interface but should be realized in SOAP. While it may allow multi-threaded access to the TCS, each operation is intended to be atomic. It resides as a system process, separate from the application and service provider processes. If the environment provides for the TCS to reside in a system process, communication between the service providers and the TCS would be via an RPC.
2. **Persistent-Storage-Access-Component (System)**
   Component covers the physical access and representation of the TCS persistent storage representation. The TSS specification separates the storage context into a per user boundary and in a system linked one. This functionality and the data representation reflect a TSS (i.e. TSP and TCG) common code component.
3. **Facade-Abstraction-Component**
   Component contains a facade factory to generate separate facade objects per calling context. This layer performs the parameter checking for the TCS-Interface.
4. **Synchronization-Helper-Module**
   Collection of some small helper classes; encapsulate the native system calls for synchronization object handling.
5. **Logical cache content handling**
   Characterize a logical TPM device per connection context and organize logical resource cache management.
6. **Logical TPM Resource handling**
   Contain a management class and resource classes for the two major handled resource types key and authorization sessions. The task is divided into a resource map management and into a resource representation unit.
7. **Setting and Policy access**
   Function and class pool to summarize operations used to access and validate setting information.
8. **Extended TPM Resource and access handling**
   Characterize a physical TPM device is designed as singleton and organize physical resource cache management. Due to the character as single entry point for all TPM operations this layer is responsible for TPM access synchronization.
9. **Error-Handling-Class**
   Helper class(es) used in the exception handling process of the TSS components (i.e. TSP and TCS). The structured exception concept will be used for error handling inside of the TSS modules.
10. **Streaming-Helper-Classes**
    Helper classes transform TCG structures into BYTE-Stream-Representation and verse versa.
11. **Physical cache strategy and organization**
    Contain a physical management classes and resource classes for the two major handled resource types key and authorization sessions. The task is divided into a resource map management and into a resource representation unit. In addition this component automatically detects the underlying TPM device version and selects the corresponding physical caching strategy and function set.
12. **Physical-TPM-Command-Module**
    Module is responsible for the TPM command stream generation (byte-stream-

generator) receiving the response and extracting the response parameter elements.

13. **TPM-Device organize management**
Component includes classes and functionality to handle TPM device specific startup and shutdown procedures. In addition it controls the consistence of the resource management of the TCS.
14. **TPM connection management**
Contain the management classes and functionality to establish the connection to the TPM device. A further task is to setup the power management control handling between IFX-TPM-Driver and TCS.
15. **Common-Module-Service**
Common functions used for TCS module management (e.g. registration, start and stop).
16. **TCS-Module-Management**
General operations used to administrate and arrange TCS module wide services (e.g. memory handling).
17. **TCG-Core-Service-TPM-Access**
Component covers the physical access and representation of the TDDL communication. Abstraction layer offer the functions to establish, operate and close the TPM communication in a local situation.
18. **TCS-Persistent-Storage (System)**
Contain the physical data representation for TCS persistent storage (on per system and access able for all users). The preferred mechanism would be XML based.
19. **TCG-TSS-TDDL**
The TCG Device Driver Library (TDDL) is an intermediate module that exists between the TCS and the kernel mode TPM Device Driver (TDD). The TDDL provides a user mode interface. Such an interface has several advantages over a kernel mode driver interface:
    - It ensures different implementations of the TSS properly communicate with any TPM.
    - It provides an OS-independent interface for TPM applications.

    Because the TPM is not required to be multithreaded, the TDDL is to be a single instance, single threaded module. The TDDL expects the TPM command serialization to be performed by the TCS. The exception to the single threaded nature of the TDDL is the Tddli_Cancel operation. The Tddli_Cancel allows the TCS to send an abort operation to the TPM.
    The TPM vendor is responsible for defining the interface between the TDDL and the TDD. The TPM vendor can choose the communication and resource allocation mechanisms between this library and any kernel mode TPM device driver.

5 OpenTC development environment configuration and requirements

5.1 Eclipse

http://www.eclipse.org
IDE consists of Editor / Compiler front-end / Debugger front-end
- Freely available for Linux and Windows

- **CDT**
  http://eclipse.org/cdt
  C/C++ Plugin for Eclipse
  Install: Use the following URL in a Site Bookmark in the update manager:
  http://download.eclipse.org/tools/cdt/releases/eclipse3.1

5.2 Version Control System

- **Subversion**
  http://subversion.tigris.org

  Directory structure (suggestion, no must-have)
  1. directory TRUNK (main latest)
  2. directory BRANCHES
  3. directory TAGS (to implement a „labeling“ mechanism)
  4. directory RELEASE (versions to be released)

- **Subclipse**
  http://subclipse.tigris.org/#subclipse
  Subversion Plug-In for Eclipse
  Installation into Eclipse: Add http://subclipse.tigris.org/update as an update site in Eclipse's update manager (which you can find in the Help menu).

- **RapidSVN**
  http://rapidsvn.tigris.org/
  Standalone subversion client available for Linux and Windows

5.3 Change- / Error-Managementsystem

- **iTracker**
  http://www.cowsultants.com/
  Java / J2EE based bug tracking system
  https Web access / Installation as Eclipse Plug-In

6 Installation Procedure for the TSS

```
OpenTC - Trusted Software Stack - Source Release

---------------------------------------------------------------------

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========

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        2.2 Software
        2.3 Installing the required software components

    3. Installation

    4. Running the TSS

    5. Building and running the testprograms

---------------------------------------------------------------------

0. Usage

 * Usage Terms
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 *   code for all modules it contains or uses.  It does not include source code
 *   for modules or files that typically accompany the major components of the
```

```
 *   operating system on which the executable file runs.
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---------------------------------------------------------------------

1. Introduction

This is the official source tree of the Trusted Software Stack (TSS)
within the OpenTC project.

The TSS is a software collection to utilize the Trusted Platform
Module (TPM) in your computer.

For details about your TPM and its capabilities visit these sites:

    www.trustedcomputinggroup.org
    www.opentc.net

---------------------------------------------------------------------

2. Prerequisites

To efficiently utilize the TSS in your computing environment must
meet some requirements in hardware and software issues:

    2.1 Hardware

    Your motherboard needs a TPM device mounted. If one is
    available, it must be activated in your BIOS.

    2.2 Software

    To compile the complete TSS the following software
    components must be available and properly installed:

        gcc                C/C++ compilers
        Xerces-C           XML Parser
        Xerces-C-devel     XML Parser files for development
        Xalan-C            XPATH extension for Xerces-C
        Xalan-C-devel      files for development
        openssl            Crypto and hashing functions
        openssl-devel      files for development
```

```
    e2fsprogs           For libuuid
    e2fsprogs-devel     files for development
    (tpm-driver)        The TPM driver behind your TPM's devnode
    gSOAP               Version 2.7.9d for IPC matters. (SP<->CS)
                        Note: communicating SP and CS need to have exactly
                         the same gSoap version,  otherwise communication
                         will fail! This can be found mainly in remote
                            scenarios.
    POSIX threads       linkable via -lpthread

For Mandriva systems it may be also needed to install

    Bison
    Flex
    include /usr/local/lib to your library path
```

2.3 Installing the required software components

This part describes some details about installing the required software components for building the complete TSS.

tpm-driver:

Firstly, you should enable the hardware module (TPM) from the BIOS setup.
The drivers are already included in the kernel since version 2.6.13.
Atmel and Infineon
chips are supported. You can load this driver by "modprobe tpm_infineon"
or
"modprobe tpm_tis". If loading of the driver is successful, you then get
a device node
like "/dev/tpm"

For other TPM drivers and older kernel versions, see
http://forum.emscb.org/phpbb/.

```
Xerces-C
Xerces-C-devel
Xalan-C
Xalan-C-devel
openssl
openssl-devel
e2fsprogs
e2fsprogs-devel
```

For these components, you can easily download their RPM files and
install them by "rpm -i filename" or you also can use the
software(package)
management tool that should be available in the most linux
distributions. This
is also the preferable way.
Here an example for installing software in SUSE 10.1 is demonstrated:

1) Select "System / Yast (Control Center)" from the startmenu
2) Select "Installation Source"
3) Select "Add / FTP" resp. "Add / HTTP"
4) Add the following entries:
    ftp://ftp.gwdg.de/suse/i386/10.1/SUSE-Linux10.1-GM-Extra
    http://ftp.gwdg.de/pub/suse/update/10.1/

```
                ftp://ftp.gwdg.de/pub/opensuse/distribution/SL-10.1/inst-source/
            5) Move the added entries to the top of the list by selecting them
and pushing "up"
            6) Push the "Finish" button

            Now it takes a little time to read in the added installation
catalogues. When it has finished
            you can simply start "Software Management", search for Xerces-c,
Xerces-c-devel, Xalan-c,
            Xalan-c-devel, openssl,openssl-devel, e2fsprogs, e2fsprogs-devel
select and install them. The
            complete installation is now done automatically and you can use the
packages.

        Another example for Fedora6:
         1) Select "Applications" in the Panel that is usually above the Desktop
         2) Select "Add/Remove Software". Then the Package Manager will start
         3) Select the tab "Search" in the Package Manager.
         4) Now you can search any software by typing the name like Xerces-c,
then you can click "apply" to install

    gSOAP:
        For gsoap, please do not use a rpm to install gsoap, because in most
cases, it just installed the
        "production" files and not the development package with the headers.
Please install gsoap by source.

        Building gsoap
        --------------

        - cd /your_gsoap_source_folder/gsoap-2.7.9d
        - ./configure

        - edit file "stdsoap2.cpp" line 3957 in folder
        /home/user/temp/gsoap-2.7.9d/soapcpp2

        replace
                    ext_data = ASN1_item_d2i(NULL, &data,
                                                 ext->value->length,
ASN1_ITEM_ptr(meth->it));
        by
                    ext_data = ASN1_item_d2i(NULL, (unsigned const char**)&data,
                                                 ext->value->length,
ASN1_ITEM_ptr(meth->it));

        save and exit the file

        - edit file "stdsoap2.cpp" line 3965 in folder
        /home/user/temp/gsoap-2.7.9d/soapcpp2

        replace
                ext_data = meth->d2i(NULL, &data, ext->value->length);
        by
                ext_data = meth->d2i(NULL, (unsigned const char**)&data, ext-
>value->length);

        save and exit the file
```

```
        - make

        - make install

        --------------

        For building gsoap, you may need flex (please also install it by source)

        Building flex
        --------------
        - ./configure

        - make

        - make install
        --------------

        PS: If you want install gsoap and flex in the default
folder(recommended), you need to
        switch to root account.
        If you have problems during the build process like missing libraries,
please
        run ./configure again after you fixed the problem (like installing
missing libraries).

----------------------------------------------------------------------

3. Installation

To install the TSS from the sources, simply invoke the build_and_install.sh
script with exactly the same options as you would supply to the configure
scripts in the subdirectories.
E.g. to install in the non-standard folder /dev/shm/opentss you can call
"build_and_install.sh --prefix=/dev/shm/opentss" and for building a debug
version you can call "build_and_install.sh --enable-debug"
Note that non-standard installation prefixes require
tweaking LD_LIBRARY_PATH (recommended) or the ld cache
(ld.so.conf, etc. - not recommended) when running the stack.

Remark: To build and install the TSS no running TPM driver is
neccessary.

----------------------------------------------------------------------

4. Running the TSS

The TSS itself is NO stand-alone program that pops up e.g. with a GUI
when it is started. The main component of the stack is the coreservice
and has to be started with administrator rights. It uses a device driver
library (DDL) to access the device driver of the TPM. Applications that
want to use the stack have to utilize the service provider shared library
(link against it) to communicate with the core service.
Each application can have its own service provider but the core service
exists only once per machine. For detailed information concerning the
structure of a TSS, please refer to the documentation provided from
the TCG (see chapter 1).

- There are three resulting binaries after installation:
```

```
  the service provider shared library (tss_sp.so) and the DDL shared library
  (tpm_ddl.so) in the 'lib' folder, and the core service daemon (coreserviced)
  in the 'bin' folder.

- The core service daemon (coreserviced) can be started as daemon
  (without any command line parameters, this is the dedicated usage)
  or as normal executable (with "--debug" as command line parameter)

- The core service dynamically loads the DDL shared library (libtpm_ddl.so).
  Therefore it is necessary that it finds the DDL shared library at runtime.
  This can be achieved by setting the LD_LIBRARY_PATH environment variable
  to the desired folder (e.g. export LD_LIBRARY_PATH=/dev/shm/opentss/lib)

- The service provider shared lib (libtss_sp.so) can be used from each
testprogram
  or any self written program and accesses the core service via a soap
interface.

Hint: When the core service is started, it writes status information with
different log levels to the systems log file(s). For openSuse systems this
is in "/var/log/messages", for a Mandriva distribution the information is
split up to several log files. If problems encounter in getting the TSS system
to work, you probably can determine the cause for this by inspecting the
log file(s).

---------------------------------------------------------------------

5. Building and running the testprograms

The source package contains a folder called "testprograms". You can build these
with the included Makefile (please adapt the needed paths before), run each
testprogram
on its own or start the "run.sh" script to run several testprograms
subsequently.
As some of the testprograms use owner authorization, please also adapt the
hardcoded
owner password in the .cpp files before compiling them (Otherwise these
testprograms
will fail due to wrong owner authorisation).

For building the testprograms, you need to make sure that the OpenTC TSS is
properly
installed, because the service provider shared library is referenced in the
building
process and will be linked to the resulting executable.
For running the testprograms you may need to set the LD_LIBRARY_PATH (if you
didn't
install the TSS in the standard folder), so that the service provider shared
library
(libtss_sp.so) can be found.
```

7 Test and Evaluation Support Programs

```
########################################################################################
testprograms using the TSPI interface of the TSP (complete TSS usage: TSP, TCS, TDDL)
########################################################################################

tspi_tpm_getrandom              get 20 random numbers from the TPM,
                                 Tspi_TPM_GetRandom, Tspi_TPM_StirRandom

tspi_tpm_getrandom_load         get 20 random numbers from the TPM, repeat 10000
                                 times, each time a new  context is used
                                (possibility to use 30 contexts in parallel)

mt_tspi_tpm_getrandom           get 20 random numbers from the TPM, using one
                                 context and 30 threads in parallel

tspi_tpm_getstatus              retrieve the states of 4 persistent flags
                                 (TSS_TPMSTATUS_SETOWNERINSTALL,
                                TSS_TPMSTATUS_DISABLEOWNERCLEAR,
TSS_TPMSTATUS_DISABLED,
                                TSS_TPMSTATUS_DISABLEPUBEKREAD) from the TPM,
Tspi_TPM_GetStatus

tspi_tpm_setstatus              disable / enable the TPM, Tspi_TPM_SetStatus

tspi_tpm_getcapability          retrieve som capabilities from TPM and TCS
                                Tspi_TPM_GetCapability,
Tspi_Context_GetCapability

tspi_tpm_takeownership          take ownership of the TPM,
                                 Tspi_TPM_TakeOwnership

tspi_tpm_clearowner             clear the TPM ownership, Tspi_TPM_ClearOwner

tspi_tpm_selftestfull           execute tpm selftest, Tspi_TPM_SelfTestFull,
                                 Tspi_TPM_GetTestResult

tspi_tpm_quote                  test the quote functionality, Tspi_TPM_Quote

tspi_tpm_getpubendorsementkey   retrieve the public part of the EK,
                                 Tspi_TPM_GetPubEndorsementKey,
Tspi_TPM_SetStatus

tspi_key_getpubkey              get the public part of the SRK,
Tspi_Key_GetPubKey

tspi_key_createkey              create a key pair within the TPM, T
                                 spi_Key_CreateKey, Tspi_Context_LoadKeyByUUID
                                 Tspi_Key_LoadKey, Tspi_Key_UnloadKey,
Tspi_Key_GetPubKey

tspi_key_wrapkey                create a key pair within the TPM and wrap it
                                 with the given wrapkey,
                                Tspi_Key_WrapKey, Tspi_Key_LoadKey
```

```
tspi_changeauth                   change the authorization data (secret) of an
                                   entity (object) and assign
                                  the object to the policy object, Tspi_ChangeAuth

tspi_changeauth_owner             change the owner authorization, Tspi_ChangeAuth

nvm_functions                     test of non volatile memory functions,
                                   Tspi_NV_DefineSpace, Tspi_NV_ReleaseSpace,
                                  Tspi_NV_WriteValue, Tspi_NV_ReadValue

transport1                        Tspi_Data_Bind, Tspi_Data_Unbind,
                                   Tspi_Data_Seal, Tspi_Data_Unseal

migtst                            test of migration functions,
                                   Tspi_TPM_AuthorizeMigrationTicket,
                                  Tspi_Key_CreateMigrationBlob,
                                   Tspi_Key_ConvertMigrationBlob

pcrtst                            test of PCR and PCR composite functionality,
                                   Tspi_PcrComposite_SelectPcrIndex,
                                  Tspi_PcrComposite_GetPcrValue,
                                   Tspi_PcrComposite_SetPcrValue,
                                   Tspi_TPM_PcrRead,
                                  Tspi_TPM_PcrExtend

tspi_context_getKeyByUUID_system    get a key by UUID from the system persistent
                                   storage

tspi_context_getKeyByUUID_user      get a key by UUID from the user persistent
                                   storage

tspi_context_registerkey_system     register a key in the system persistent
                                   storage

tspi_context_registerkey_user       register a key in the user persistent
                                   storage

tspi_context_loadkeybyblob          load a key from a keyblob,
                                   Tspi_Context_LoadKeyByBlob

provoke_error      test some functions that must give an error:
                   - close the default policy object
                   - close the TPM object / close the policy object of the TPM
object
                   - create 2 keys and one policy, assign the policy to both
keys,
                     create first key and then delete the policy, create key 2
fails
                   - assign a new policy to the context object
                   - assign a new policy to the tpm object

key_auth_chain     This test creates 3 keys in a hierarchy, the middle of which
requires auth.
                   This is meant to test the TSS_LOADKEY_INFO functionality. The
TCS should
                   try to load key 2 first and notice that its parent needs
loading. When it
```

```
                   tries to load key 1, it should see that there's auth data
there and return
                   a TSS_LOADKEY_INFO struct to the TSP. The TSP should
transparently handle
                   this structure to get...

                   SRK
                     \
                      hKey0 (no auth)
                        \
                        hKey1 (auth)
                          \
                          hKey2 (no auth)

callback           test HMAC callback, XORENC callback and TAKEOWNERSHIP
                                 callback functionality

hash               tests covering the hash object: creation,
                                 Tspi_Hash_SetHashValue,
                   Tspi_Hash_GetHashValue, Tspi_SetAttribData, Tspi_Hash_Sign,
                   Tspi_Hash_VerifySignature

enc_dec            test Tspi_EncodeDER_TssBlob and Tspi_DecodeBER_TssBlob
                                 functions


################################################################################
######
basic TPM setup (using only TDDL, no TSP and no TCS), TCS must not be running
################################################################################
######

inittpm         TPM_Startup, TPM_PhysicalPresence, TPM_PhysicalPresenceSet,
                                 TPM_PhysicalEnable
                TPM_SetDeactivated (false), TPM_SelfTestFull, TPM_GetRandom,
TPM_GetCapability (TPM_CAP_VERSION)

startuptpm      TPM_Startup, TPM_SelfTestFull, TPM_GetRandom, TPM_GetCapability
(                                TPM_CAP_VERSION)

forcecleartpm   TPM_Startup, TPM_PhysicalPresence, TPM_PhysicalPresenceSet,
                                 TPM_ForceClear,
                TPM_SelfTestFull, TPM_GetRandom, TPM_GetCapability
                                 (TPM_CAP_VERSION)
```

8 Test Procedures for the Development Phase

This chapter gives an overview of the tests that have been developed and used for testing and quality assurance of the API's of the TCG Software Stack (TSS) within the project OpenTC. This comprises the TSPI (TSS Service Provider) and TSS Core Service. The TPM drivers are not part of this activity because they are already available as part of the Linux kernel 2.6.16 and later.
This package proposes a setup for the test environment and implementation hints so that the test cases developed by different people will be consistent in their handling.
The testing generally is done by calling from the test harness the appropriate functions provided by the TPM and TSS components via the automated script environment.
The actual implementation of the tests is done by writing scripts for an interpreter on top of an automatically generated TSPI wrapper.

8.1 Glossary of Terms

Terms/Abbreviations	Definition
Client Area:	
Platform Security Chip	The TPM chip itself
Security Platform	Is a platform equipped with a Platform Security Chip
Security Platform User	This is a platform user who is also using the Security Platform.
Security Platform Owner	Is the owner of the Platform Security Chip.

8.2 Test environment

8.2.1 Security Platform:

- The Security Platform , which carries the TSS stack as testobject, requires a TPM chip, like the Infineon TPM SLB9635TT1.2 be setup properly with the TPM firmware V1.00 or higher and corresponding BIOS integration support (e.g. ACPI).

8.2.2 External/existing modules for Security Platform:

- Compiler: gcc version 4.1.0-25 and higher
- Linux Kernel on target system: 2.6.17 or higher
- Crypto-Library: openssl 0.9.8a-16 + openssl-devel 0.9.8a-16
- SOAP-Library (used for CS and SP SOAP-Interface): gSoap -> gsoap_2.7.6e.tgz
- XML-Library (used for persistent storage of CS and SP):
  Xerces -> Xerces-c 2.7.0.11+ Xerces-c-devel-2.7.0-11
- XPATH extension for Xerces: Xalan -> Xalan-c 1.10-10 + Xalan-c-devel 1.10-10
- Generation of UUIDs: libuuid -> e2fsprogs 1.38-25 +e2fsprogs-devel 1.38-25
- Transports messages to and from remote objects using the SOAP protocol.
- Ruby interpreter v1.8.5
- Native 32 Bit computer platforms for carrying test harness and test object

8.2.3 Test environments for different test methods

For different test purposes and scenarios we use adapted environments:

8.2.4 PHP –interface for browser supported testing

This allows an easy interfacing to standard browsers and therefore a manual user supported test execution especially for error identifying and isolation. Additional trace monitoring assists in test reproduction and test documentation.

8.2.5 Ruby test environment interpreter for automatic test sequencing

The Ruby interpreter can be used to offer an automatic test execution support for large scale regression tests and similar activities

Ruby is a relational language developed by Jones and Sheeran for describing and designing circuits. Ruby programs denote binary relations, and programs are built-up inductively from primitive relations using a pre-defined set of relational operators. Ruby programs also have a geometric interpretation as networks of primitive relations connected by wires, which is important when layout is considered in circuit design. Ruby has been continually developed since 1986, and has been used to design many different kinds of circuits but also test language environments.

Ruby is a pure, untyped, object-oriented language—just about everything in Ruby is an object, and object references are not typed. People who enjoy exploring different OO programming paradigms will enjoy experimenting with Ruby: it has a full metaclass model, iterators, closures, reflection, and supports the runtime extension of both classes and individual objects.

Ruby is being used world-wide for text processing, XML and web applications, GUI building, in middle-tier servers, and general system administration. Ruby is used in artificial intelligence and machine-learning research, and as an engine for exploratory mathematics.

Ruby's simple syntax and transparent semantics make it easy to learn. Its direct execution model and dynamic typing let you develop code incrementally: you can typically add a feature and then try it immediately, with no need for scaffolding code. Ruby programs are typically more concise than their Perl or Python counterparts, and their simplicity makes them easier to understand and maintain. When you bump up against some facility that Ruby is lacking, you'll find it easy to write Ruby extensions, both using Ruby and by using low level C code that adds new features to the language. We came across Ruby when we were looking for a language to use as a testing and specification tool.

The Ruby approach to test design is to derive implementations from specifications in the following way. We first formulate a Ruby program that clearly expresses the desired relationship between inputs and outputs, but typically has no direct translation as a test. We then transform this program using algebraic laws for the relational operators of Ruby, aiming towards a program that does represent a test environment. There are several reasons why Ruby is based upon relations rather than functions. Relational languages offer a rich set of operators and laws for combining and transforming programs, and a natural treatment of non-determinism. Furthermore, many methods for combining circuits (viewed as networks of functions) are unified if the distinction between input and output is removed.

8.3 Tracing and Protocol

The components TCS and TSP do not write any trace information. For the purpose of tracing, a special tool/environment will be used, if necessary.

The test script and all results of each test case shall be written into a protocol file. The protocol has the same tags as the test protocols of the TSS, so that only one style sheet for all test protocols will be needed.

8.4 Test Development

8.4.1 Formal Requirements for the Test Plan

The test cases are grouped into test subjects. For each test subject, there is a subchapter in this document. This sub chapter contains a short overall description of the test subject and a table with one row for each test case.

The first column denotes the test case priority. The second one contains a unique identifier for the test case, the third one a description of the test case that should be sufficient to implement the corresponding test script. The third column contains either all tested commands of that test case (good cases) or the expected result for the fault cases.

8.4.2 Formal Requirements for the Test Scripts

To achieve a certain homogeneousness of the test scripts independent on the developer and to allow for an automated checking of the test results, the following rules shall be followed.

The name of a test script shall include the unique identifier of the test case it implements. It shall be obvious from the script's name, which test case it realizes.

The suffix of a test script shall indicate its use.

*.rb for standalone scripts that can be invoked from the command line

*.inc scripts to be included in other scripts that define commonly used variables

If scripts contain possible dependencies they shall be realized as includable. A test case using this subroutine might then only contain the unique test case identifier and include the subroutine script.

For example encryption and decryption: the functionality of encrypting shall be put in a subroutine script as well as the functionality of decrypting. Then both of them shall be included by the standalone script thus calling the functions in the appropriate order.

Each standalone script shall release all variables by means of a instruction before terminating so that various standalone scripts can be invoked by means of include instructions by a master script.

Each standalone script that represents the main script of a test case must include a reference to the unique test case identifier by containing a line

<Test-Id> unique identifier </Test-Id>

which is an tag that will be treated as a comment and written into the protocol file without change.

Each script must contain two version information fields which can be automatically added to the protocol file. That means, each time a script is checked in into the database (and it was modified in a major manner), its version number must be increased by the author and the current date is set.

8.5 General Requirements for the Test Scripts

Hardware TPM's do not get a reset from software and therefore do not clear any previously set values, including PCR's and keys.

If a test script uses any PCR values, it must set the PCRs with an Extend command. At the end of each script all keys loaded by that script shall be evicted to avoid problems running on hardware TPM.

8.5.1 Hints for test script development

See chapter 3.5 for already implemented helper functions.

8.6 Guidelines for Test Development

- Identify a test subject
- Insert a subchapter into chapter TSPI of this document
- Write a short description of the test subject
- Develop the test scripts according to the table in the test plan. Usually, one test script will contain one test case.
- Fault test cases usually contain more than one test case in each row and each test script.
- Debug the test scripts with the help of the Scripting Debug Tool.

8.7 Helper functions

Scripting environment does not handle by default TCG specific structured data but only byte streams. To achieve the functionality of this the TSPI-Wrapper exports classes, to implement some helper functions.

These helper functions can be realized as script functions first and may later be included in the wrapper module.

8.7.1 Defined helper functions:

These helper functions are implemented in the scripting dialect and can be found in the generic folder.

- Different compare methods (“Test” instruction)
- Various protocol functions
- Retrieve internal version of all included scripts
- ReadFromFile
- WriteToFile
- PrintData
- Bin2String
- AppendArrays

- Functions for ASN.1 handling
- Functions for extracting parameters from TCPA structures

8.8 Scripting library

All data types in the interface handled as pointer have to be handled by the corresponding class objects in the scripts.

8.9 Provoking Fault cases

To be able to provoke fault cases, it is desirable to create a special TDDL library capable of changing the handled data.

As a next step , still outside the scope of this document, a special test environment will be developed for provoking such errors and storing these test results.

Driven by a separate text (ini) file, this test environment and library will change, delete or insert (ranges of) bytes of specified commands which were send from the TPM to the TSS.

8.10 Running and Exercising the Tests

Running the Tests

- Open a command window
- change to the script directory within <test subject>
- run the test script file
- archive the results in the archive directory

8.10.1 Test coverage

All test cases from this test plan shall be imported into a test coverage database.

The test results of all final tests will be imported into the same test coverage database.

8.11 Presentation of Test Results

The test results are primarily delivered in the form of the protocol files written by helper functions.

As the protocol file contains tags for certain attributes of the test cases and their results, it is possible to extract various summarizing reports from the protocol file.

Sample protocol file:

****

Test script: IS2_TSP_001_CreateKey1.rb

Protocol: ..\TssProtocols\ IS2_TSP_001_CreateKey1.pro

TSS Core Service: ..\TCG\TPM-SW\TSS\bin\TCS.exe
version: 2.0.0.0
last modified: 26.10.2005 16:20:11

TSS Service Provider: ..\TCG\Tsp\tsp.dll
version: 2.0.0.0
last modified: 02.12.2005 15:07:28
****
<Test-Id> IS2_TSP_001_CreateKey1 </Test-Id>

<Script-Revision> 1.0.0 </Script-Revision>
<Script-Date> 10.10.2006 </Script-Date>
****
\# Test started at 10.10.2006 16:05:59

****
TSS version 1.2 selected
Firmware version: 1.00

****
System:

Kernel: 2.6.16.13
Xerces:2.7.0-11
Xalan-C: 1.10-10
GSOAP: 2.7.7
Ruby: 1.8.5
****
<Test-Id-Start> IS2_TSP_001_CreateKey1 </Test-Id-Start>

TspConnect

TspConnect succeeded !

TspCreateObject(4,0)

TspCreateObject succeeded !

TspCreateObject(2,67108864)

TspCreateObject succeeded !

TspKeySRK.GetPolicyObject succeeded !

TspSRKPolicy.SetSecret succeeded !

TspCreateObject(2,0)

TspCreateObject succeeded !

TspCreateObject(1,1)

TspCreateObject succeeded !

TspPolicyUsage.AssignToObject succeeded !

PolicyUsage.SetSecret succeeded !

TspCreateObject(1,2)

TspCreateObject succeeded !

TspPolicyMigration succeeded !

PolicyMigration.SetSecret succeeded !

TspCreateKey succeeded !

TspKey.GetAttribData succeeded !

keyBlob:

0x30, 0x82, 0x01, 0xEB, 0x02, 0x01, 0x01, 0x02, 0x01, 0x01, 0x02, 0x04, 0x00, 0x00, 0x01, 0xDB, 0x04,
0x82, 0x01, 0xDB, 0x01, 0x01, 0x00, 0x00, 0x00, 0x15, 0x00, 0x00, 0x00, 0x06, 0x01, 0x00, 0x00, 0x00,
0x01, 0x00, 0x02, 0x00, 0x03, 0x00, 0x00, 0x00, 0x0C, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00, 0x00, 0x02,
0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x2C, 0x00, 0x02, 0x09, 0x00, 0x8F, 0xB4, 0x77, 0x65, 0x99,
0x63, 0xF3, 0x84, 0x63, 0x58, 0xE3, 0x9C, 0x4A, 0x89, 0x74, 0x50, 0xBB, 0x1C, 0xD7, 0x5D, 0x8F, 0xB4,
0x77, 0x65, 0x99, 0x63, 0xF3, 0x84, 0x63, 0x58, 0xE3, 0x9C, 0x4A, 0x89, 0x74, 0x50, 0xBB, 0x1C, 0xD7,
0x5D, 0x00, 0x00, 0x00, 0x80, 0x8C, 0x9C, 0xCC, 0xF0, 0xD9, 0x77, 0x12, 0xE1, 0x72, 0x21, 0x42, 0x93,
0xA7, 0x75, 0x54, 0x6C, 0x45, 0x33, 0xFF, 0x26, 0x1F, 0xA1, 0xC9, 0xDF, 0x6F, 0x31, 0x89, 0x35, 0x47,
0x94, 0x7D, 0xEF, 0x1D, 0xED, 0xF6, 0x15, 0x5F, 0x97, 0x19, 0x30, 0x09, 0x87, 0x28, 0x58, 0xE1, 0x46,
0x4A, 0x97, 0x4A, 0xE9, 0x5B, 0xB8, 0x59, 0x12, 0xAC, 0x21, 0x51, 0xF6, 0x4A, 0x0D, 0x4F, 0xE5, 0x84,
0x76, 0x6D, 0xAC, 0x6F, 0xE1, 0xF2, 0x5F, 0x43, 0x27, 0xB4, 0x8E, 0x16, 0xB7, 0xCB, 0x52, 0x07, 0x01,
0x9D, 0xFB, 0xC3, 0x9D, 0x52, 0xAE, 0x29, 0x62, 0x0E, 0xDA, 0x67, 0x8F, 0xAD, 0x68, 0x13, 0x2E,
0xF3, 0x9C, 0x36, 0x4F, 0xA2, 0x92, 0x22, 0x92, 0x12, 0x2D, 0x1D, 0xF0, 0xE2, 0x47, 0x78, 0x71, 0xFE,
0xD2, 0x9F, 0x8B, 0x14, 0x49, 0xFF, 0x59, 0x8B, 0x56, 0xC4, 0xED, 0x4F, 0xAF, 0x99, 0x09, 0x00, 0x00,
0x01, 0x00, 0x36, 0xF4, 0xF2, 0xB8, 0xFC, 0xD3, 0x83, 0xD1, 0x8F, 0xFD, 0x24, 0x97, 0xD9, 0x97, 0xDB,
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0x23, 0xA9, 0x23, 0xAF, 0xF4, 0xCA, 0x0E, 0x2A, 0x43, 0xC5, 0x04, 0xE9, 0x1D, 0xA5, 0x1C, 0x35, 0x73,
0x8E, 0x4B, 0x11, 0xB0, 0xBD, 0x97, 0x14, 0x8D, 0x58, 0x17, 0xD2, 0x9A, 0xDA, 0x0A, 0xE4, 0x64,
0x10, 0xFE, 0xE3, 0x2E, 0xB4, 0x76, 0xF4, 0x10, 0x80, 0x0B, 0x50, 0xE5, 0x60, 0x76, 0x68, 0x81, 0xBE,
0x11, 0x58, 0x10, 0xBA, 0xA0, 0xC0, 0x64, 0x47, 0x8E, 0x0D, 0xA9, 0xEC, 0x07, 0x42, 0x36, 0xD5,
0x18, 0x0D, 0x73, 0x8F, 0x4D, 0x7C, 0x53, 0x7C, 0x40, 0x78, 0x4A, 0x60, 0x0E, 0x70, 0x75, 0x46, 0x61,
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0xBF, 0x24, 0x7D, 0x15, 0x56, 0x20, 0x30, 0x69, 0xFB, 0x98, 0x43, 0x39, 0xDE, 0xCD, 0x0F, 0x9D, 0x87,

0x30, 0xB4, 0xC1, 0xD7, 0x37, 0x83, 0xFC, 0xE7, 0xAE, 0x56, 0x48, 0xAC, 0x8D, 0xC1, 0x40, 0x1E, 0x95, 0x44, 0xD2, 0x60, 0x06, 0x4B, 0xD7, 0x35, 0x91, 0x80, 0x3D, 0xA7, 0x64, 0x60, 0x1C, 0x4D, 0x08, 0x25, 0xE8, 0x11, 0x12, 0x3E, 0xB5, 0xD0, 0xBB, 0x65, 0xDF, 0xCD, 0xB2, 0x29, 0x14, 0x12, 0xC2, 0xA3, 0x68, 0xF3, 0xF1, 0x0D, 0x44, 0xB3, 0x19, 0x15, 0xC2, 0x2C, 0xA8, 0xD1, 0xCA, 0xF2, 0xB9, 0x00, 0x2F, 0x2B, 0x2F, 0x9F, 0xE0, 0xE6, 0xA7, 0xDC, 0x49, 0xB5, 0xEC, 0x71, 0x88, 0x3E, 0x54, 0x0C, 0x50, 0xE0, 0x79, 0x6D, 0x07, 0x6E, 0xB4, 0x38, 0xD2

<Test-Id-End> IS2_TSP_001_CreateKey1 </Test-Id-End>

<Test-Id-Summery-Start> IS2_TSP_001_CreateKey1 </Test-Id-Summery-Start>

```
*************************************************
# TEST ERROR(S):    0
# TEST WARNING(S):  0
# TEST INSTRUCTION(S): 14


# TEST FINISHED:     10.10.2006   16.06.50
# TEST DURATION:     51 seconds
*************************************************
```

<Test-Id-Summery-End> IS2_TSP_001_CreateKey1 </Test-Id-Summery-End>

9 Test management environment based on the script language RUBY

In addition to the PHP based test interface , which has advantages for manual testing and fast generation of result reports, we used also the well known RUBY environment for testing.

9.1 Motivation and execution

For a full coverage of the functionality and behaviour tests of the Linux TSS stack within the OpenTC project, we use two different test methods and implementations. Small and compact code sequences are generated in the target programming language C as well as for the test environment based on the RUBY script language which use only small and compact functional of the TSS service provider. With such high granularity tests we will minimize the risk to ignore errors within the execution protocols. From the point of the Service provider (SP) both methods look nearly identical, because the complementary test process is either an executable program or an shared object from the universal test environment.

This run time library is following certain stringent rules, for allowing the RUBY interpreter to feed through and converting the script calls of the ruby interpreter.

Amongst the many available script languages for Linux, Ruby has been selected, because this language is consequently object oriented , the scripts are easily to read and the generation of a linkage library to connect to the TSS SP is very much supported by automatic code generation means.

9.2 Requirements for run time environment

9.2.1 The Ruby Interpreter

We use the self compiling Ruby interpreter vers. 1.8.5 for all applications within our project. This standardized interface makes sure, that also any external error gives similar results in any case.

For generation of Ruby a predefined script is available:

$OPENTSS_DIR/../../testtool/tsstest/shared/build_all

It generates the interpreter as well as the support program “swig”. During successful generation the script also establishes within the test directory

„$OPENTSS_DIR/build/bin“ symbolic links to the support programs below

$OPENTSS_DIR/../../testtool/tsstest/shared/ruby/ruby_runtime/bin

and

$OPENTSS_DIR/../../testtool/tsstest/shared/swig/swig_runtime/bin

The testing personal as well as the developers have to have the target directory inside their search paths of the shell on a location before he system definition parts.

9.2.2 Writing test scripts

For testing the TSS functions with the help of Ruby, every scripts needs only one test definition file, e.g.:

Require "../generic/otc_environment.inc"

For example „otc_environment.rb“ includes a class of logic elements, several TSS constants and the Ruby TSS Wrapper. This behaviour has advantages for TSS. Other directory structures would require adaptations of the scripts.

[Ruby] http://www.ruby-lang.org/en/ Ruby language, a programmers best friend; Official ruby page

[RubyD] http://www2.ruby-lang.org/en/20020102.html , the Ruby download page

10 Testing by third parties inside the OpenTC project

The Budapest University of Technology and Economics (BME) Department of Measurement and Information Systems is responsible within the OpenTC WP 7 'Software Development Support, Quality, Evaluation and Certification' for the manual and automated security testing of OpenTC software components.

BME carries out testing on different targets during the course of the project; and also on the TSS. For this ToE a combined approach was chosen, for the API-level analysis at the TSPI-interface level of the TCG Software Stack implementation both black-box and white-box mode testing will be executed using the automated security testing tool Flinder.

The main goal of the testing is to evaluate the TSS at the TSPI level using both black-box and white-box techniques. By doing this BME will gain information about integrity and interoperability properties of the Service Provider (SP) and Core Service (CS) parts of the TSS implementation.

Test process overview

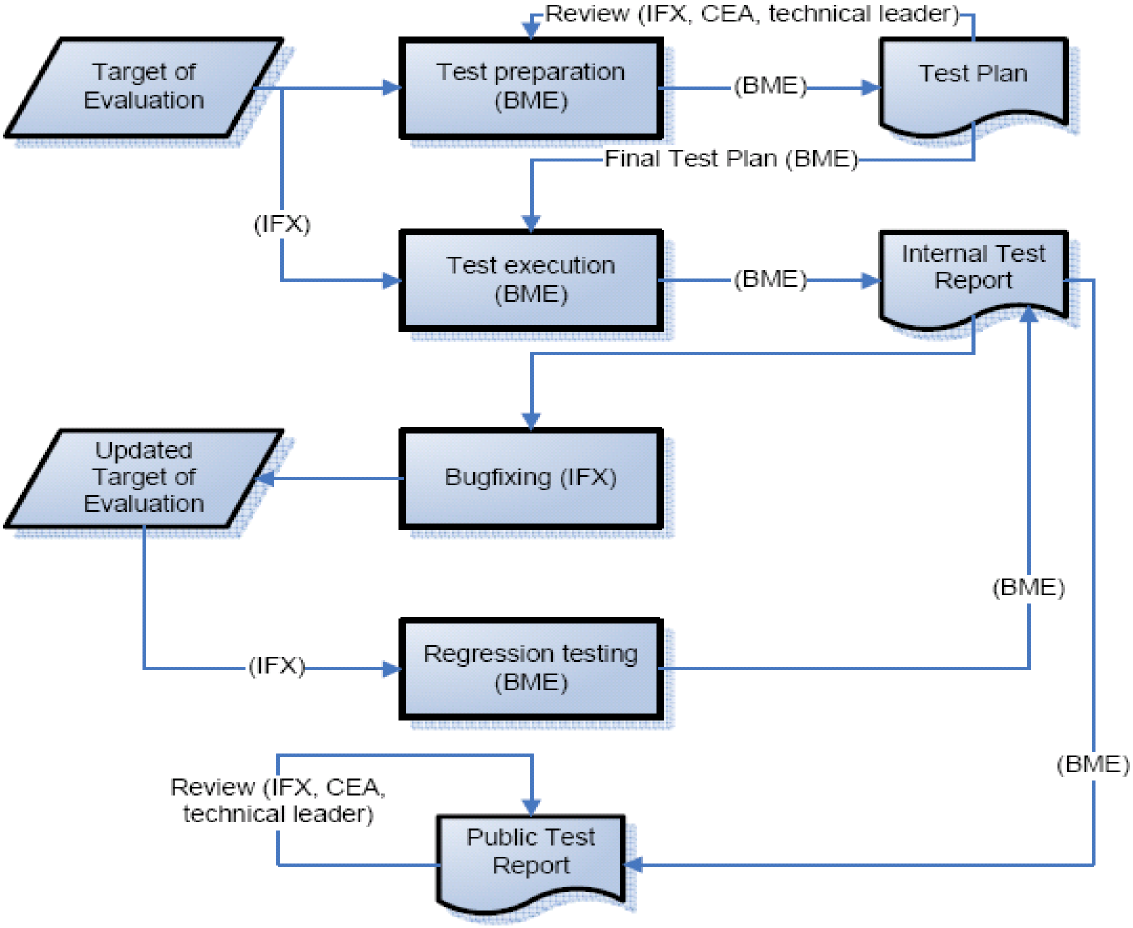

Figure 5:Test process overview

This section details the test process that will be followed by BME during the execution of testing of the OpenTC Infineon TSS implementation. The following steps constitute to the test process:

SECURITY OBJECTIVES

Concerning the Infineon TSS implementation BME carries out an API-level security testing using the automated security testing tool FIINDERS. The overall goal of the testing is to focus on typical security-relevant programming bugs and detect their presence in the Target of Evaluation in an automated fashion.

Regarding this API-level automated security testing we formulated two types of security objectives:

1) TCG-related security objectives build a wrapper around the security requirements specified in the TCG documents and
2) 2) implementation-related security objectives focusing on the properties of the actual piece of software being under scrutiny.

The goal of the execution of the automated security testing will be to assess, to what level the Infineon implementation fulfills these requirements.

Test approaches

BME will carry out automated security testing using the Flinder [FLINDER] tool. This tool was selected after having carried out a comprehensive study in the field of automated security testing utilities.

Two venues shall be considered for testing the TCG Software Stack (TSS) implementation:

• The first approach targets the TCG Service Provider Interface (TSPI) and will employ white-box testing techniques for vulnerability assessment. With this method we will be able to evaluate integrity issues of the Service Provider (SP) part of the TSS implementation.

• Other means shall be used for the second approach: black-box testing of the SOAP transport layer. This time, deeper levels of the TSS are scrutinized for potential threats. The SOAP communication link is targeted because it is the interface to the TSS Core Services (TCS) layer implemented in the `coreserviced` process. This approach will enable use to assess the security and interoperability of the Core Service (CS) part of the TSS implementation.

Black-box testing at the SOAP connection level

The implementation of the TSS is realized by two communicating processes. Driving the kernel device driver and providing the core service functionality is provided by the `coreserviced` demon server process. Two TSS layers are implemented in this process, the TDDL and the TCS. The `coreserviced` process exposes a programming interface, which clients can access through the SOAP protocol.

Flinder starts the test program, but now instead of hooking the source code, the SOAP communication is intercepted. A SOAP proxy is inserted into the data stream, which channels data to Flinder. The intercepted data is modified and then routed back to its original destination.

The main advantage of this procedure is that now the implementation of the coreserviced is under investigation, and not that of the client process. In this setting malfunctions or crashes of the client process do not mask potential failures in the core service demon.

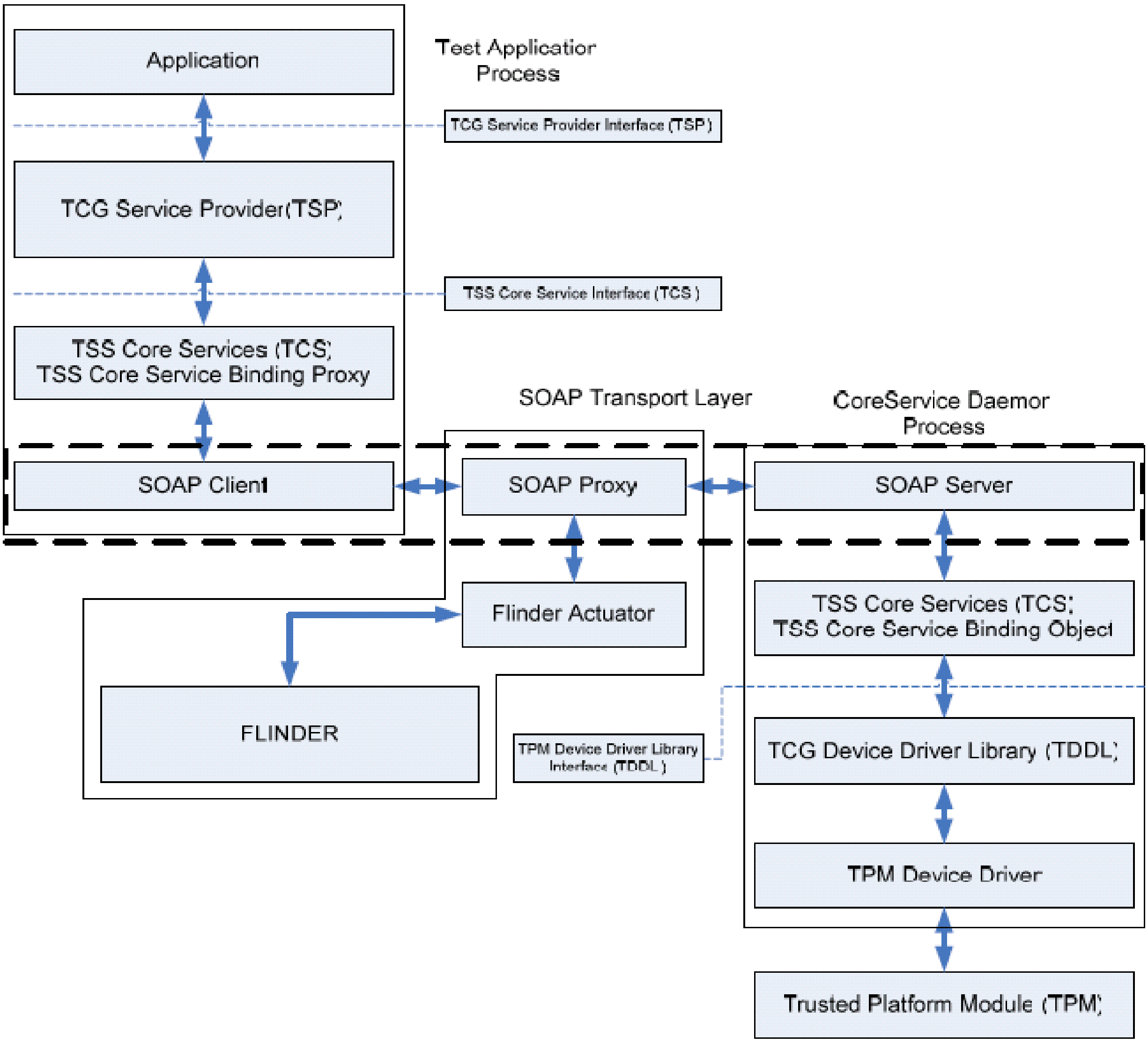

Figure 6 :SOAP transport level hooking

The detailed description and results from these test procedures will be available as deliverable report from OpenTC WP7.

11 TPM Controller: TPM Management and Control SW package

The „TPM Controller“ is a GUI application that helps the user with the initial startup of the TPM usage. The intention of the tool is not to provide a complete set of functions for handling all capabilities of the TPM nor displaying all possible TPM internal values, but to "control" the basic functionality for further usage of the TPM. There are some other applications handling the former issues, like the "TPM Manager" (http://sourceforge.net/projects/tpmmanager/) or the "TPM Monitor" (http://sourceforge.net/projects/tpmmonitor/).
The "TPM Controller" tool arised as a result of the OpenTC EU project and is hosted on their homepage http://www.opentc.net/ . It provides the possibility to take, change and clear the ownership of the TPM, which are probably the main things to do when initiating a TPM. In opposition to these other packages it uses exactly the official functional TSS1.2 specification from the TCG.
Further on the current version of the used TSS, the actual TPM firmware version and the vendor name of the TPM are displayed. On the "Status" tab the status of Activation, Enable/Disable and if an owner is already set are displayed.
With the reset button on the "Reset" tab the owner of the TPM is able to reset the so called "Pin Failure" count.
The "Certificate Chain" tab tries to verify the TPM built-in endorsement certificate.

11.1 Preconditions

„TPM Controller“ is a Linux Tool developed and tested on openSuse 10.1 / 10.2, but should work also with other Linux distributions and could be easily ported to Windows, since the used GUI toolkit is available for both platforms. It explicitly uses the OpenTC Trusted Software Stack for TPM 1.2 developed by Infineon. A working installation of the stack is indispensable.
For the GUI toolkit the open source version of Trolltech Qt 4.2.x was chosen. Therefore it is necessary that a working version is installed on the machine.
An additional dependency relies on the OpenSSL crypto library, that is used for cryptographic functionality.

11.2 Build & Run

If all preconditions are met, simply run „build.sh“ on the command line to build the complete „TPM Controller“ GUI application from source.
To run the „TPM Controller“, simply type „./tpmcontroller“ in the source code folder and the tool starts up with a modal dialog including several tabs with all the functionality explained in the following chapters. Obviously the tool can be simply copied to a user desired location and run from there.

WP03c.2 High-level key manager service design specification

Project number	IST- 027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Internal document

Deliverable reference number	IST-027635/D03c.2/FINAL 2.00
Deliverable title	High-level key manager service design specification
WP contributing to the deliverable	WP3
Due date	Dec 2006 - M12
Actual submission date	Jun 2008 - M32 (revised version)

Responsible Organisation	Politecnico di Torino
Authors	Gianluca Ramunno and Roberto Sassu (POL)
Abstract	Key and data Management Adaptation layer (KMA), formerly “High-level Key Manager service”, is intended to be a software system built upon TPM and TSS, whose goals are protecting keys and other sensitive data for generic applications and services and binding the access to the protected information to the integrity of the system. This document consists of a high-level requirements specification for KMA in terms of use cases description and a high-Level software architecture description in terms of use cases implementation.
Keywords	Open_TC, KMA, TPM, TSS

Dissemination level	Public
Revision	FINAL 2.00

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

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1 Motivation and Problem Description

There are several widely used application that can take advantage from using the Trusted Platform Module (TPM) [1] as hardware cryptographic device and root for a protected storage. Typical applications are those implementing security protocols (like SSH [2], IPsec [3]) or interfaces (like PKCS#11 [4]). A first approach to enhance such applications with the TPM could be replacing some cryptographic primitives implemented in software with the corresponding ones provided by the TPM. However the latter is a slow device and the primitives and algorithms available for applications are only few; therefore, depending on cryptographic primitives and algorithms required by applications, only some of them can actually exploit primitives and algorithms implemented in hardware.

The TPM also provides mechanisms to implement a protected storage for keys and other data, through a chain of encrypted keys up to the Storage Root Key (SRK) key, permanently protected by TPM. These features allow the creation of an arbitrary information tree that may contain asymmetric keys used directly by the TPM and other keys and data to be used by the application. TPM keys can be stored directly on a permanent storage device (like a hard disk) or through the protected storage provided by TCG Software Stack (TSS) [5], in which case the stored TPM keys are identified by UUIDs. However each application has its own information model for data, keys and certificates, which are usually stored in different files. Therefore an approach based on protection at the file level can be generic enough to support most of applications or services.

TPM also provides the basic mechanism (sealing) to bind sensitive data to the integrity of the platform components, whose measurements are recorded in the Platform Configuration Registers (PCRs).

This document describes the use cases for Key and data Management Adaptation layer (KMA), formerly “High-level Key Manager service”, a software system built upon TPM and TSS, whose goals are protecting keys and other sensitive data for generic applications and services and binding the access to the protected information to the integrity of the system.

Specific objectives for KMA are:

- access to protected data granted only if the integrity of system and the application/service requiring the access are verified
- (optional) access to protected data granted only if the system and the application/service have specific values for selected run-time properties (e.g. the user currently logged in)
- isolation between protected data of different applications/services at run-time to prevent that, if an application gets compromised (e.g. because of a flaw) and the protected data can be accessed in memory by an attacker, the protected data of all other applications/services can be accessed by the attacker
- data protection robust against off-line attacks to the storage device
- generic protection mechanism for data files that does not require any modification to the application/service at build time, in order to use KMA with standard distributions
- support for the access to TPM keys bound to system/application integrity and

properties, requiring minimal modifications at build time for application directly using the TPM keys

- seamless upgrade of the operating system and the protected applications while keeping the data protection
- support for platforms with a single operating systems running or (optionally) full virtual machines

2 Security Environment

This section describes the security aspects of the environment in which the product is intended to be used and the manner in which it is expected to be employed.

2.1 Assumptions

A description of assumptions shall describe the security aspects of the environment in which the Target of Evaluation (TOE) will be used or is intended to be used. This shall include the following:

- *information about the intended usage of the TOE, including such aspects as the intended application, potential asset value, and possible limitations of use; and*
- *information about the environment of use of the TOE, including physical, personnel, and connectivity aspects.*

/A 10/ Trusted Administrator

The security administrator of the system is non-malicious.

/A 20/ Correct hardware

The underlying hardware (e.g., CPU, devices, TPM, ...) does not contain backdoors, is non-malicious and behaves as specified.

/A 30/ Physical attacks

Physical attacks against the underlying hardware platform do not happen.

/A 40/ TOE Binding

The IT-environment offers a mechanism that allows the TOE to store information such that it cannot be accessed by another TOE configuration. Example mechanisms are the sealing function offered by a TPM as specified by the TCG in combination with an authenticated bootstrap architecture, or a tamper-resistant storage in combination with a secure bootstrap architecture.

/A 50/ No man-in-the-middle attack

A physical attack that relays the whole communication between a local user and the I/O devices to another device does not happen.

/A 60/ TCB components

The Trusted Computing Base consists of the TPM, a trusted boot loader (implementing the authenticated boot) and the kernel of the Operating System.

2.2 Threats

A description of threats shall include all threats to the assets against which specific protection within the TOE or its environment is required. Note that not all possible threats that might be encountered in the environment need to be listed, only those which are relevant for secure TOE operation.

A threat shall be described in terms of an identified threat agent, the attack, and the asset that is the subject of the attack. Threat agents should be described by addressing aspects such as expertise, available resources, and motivation. Attacks should be described by addressing aspects such as attack methods, any vulnerabilities exploited, and opportunity.

If security objectives are derived from only organizational security policies and assumptions, then the description of threats may be omitted..

/T 10/ TCB Replacement

An adversary may try to access protected data by replacing the OS kernel or the boot-loader by another system under its full control of the adversary.

/T 20/ TCB Integrity Violation

An adversary may try to access protected data by violating the OS kernel or the boot-loader integrity such that access control can be bypassed.

/T 30/ TOE Replacement

An adversary may try to access protected data by replacing the TOE by another system under its full control of the adversary.

/T 40/ TOE Integrity Violation

An adversary may try to access protected data by violating the TOE’s integrity such that access control can be bypassed.

/T 50/ Malicious Device Drivers

An adversary may try to access protected data by (directly or indirectly) installing a device driver that uses hardware functions (e.g., direct memory access) to access protected data.

/T 60/ Virtualization

An adversary may try to access protected data by running the OS on top of a Virtual Machine Monitor (VMM) that is under control of the adversary.

/T 70/ Trojan Horse

An adversary may try to get access to protected data by deceiving Administrators or Users (see Section 1.3.2) such that a application under control of the adversary claims to be a(nother) trusted application.

/T 80/ Unauthorized User

An unauthorized user may use an application to read or modify protected data owned by another user.

/T 90/ Unauthorized Administrator

An unauthorized user may use a management functionality of the KMA to grant itself access to protected data.

/T 100/ Unauthorized Data Access

An unauthorized application may read or manipulate user protected data persistently stored by another application.

/T 110/ Unauthorized Memory Access

An unauthorized application may read or manipulate user information stored within the address space of another application.

/T 120/ Exploit

An malicious entity may use an exploit of an uncritical application to gain access to protected data.

/T 130/ Unauthorized Data Binding

An unauthorized application may bind user data to the platform or a specific software configuration such that it is not available after a software update or a change of the platform.

/T 140/ Replay Attack

A malicious user may reset the state of an application, e.g., the licence, by replaying an older state, e.g., a backup.

/T 150/ Denial of Service

An adversary may try to prevent that authorized users can use a secured application or service by denial of service attacks against TCB or TOE.

3 Functional Requirements (Use Case Model)

3.1 Goal

The general idea, underlying KMA architecture, is to enable applications and services critical for a platform to use the TPM for protecting their keys and data.

The goal is that these applications can access their data if and only if the platform and themselves are running in a trusted status (defined by the administrator) and if they own certain properties' values.

3.2 Target Groups

Defines the users/other components that wish to use the product.

- Home user (Single-user platform at home)
- Employee (Multi-user platform in enterprise environment)
- Server (Multi-user platform in enterprise environment)

3.3 Roles and Actors

In this section we define different roles and actors important for the use case model. Actors are parties outside the system that interact with the system; an actor can be a class of users, roles users can play, or other systems. Note that, depending on the use case, some parties or actors may not be involved.

KMA administrator: the KMA administrator is an entity who defines the allowed configurations of the underlying platform, also including patches/updates. The administrator is also the owner of the TPM and thus is aware of the owner authorization information. Typical examples are a system administrator for an enterprise or an end-user owning a personal platform.

Secured application: an interactive application or a non-interactive service running on a platform with KMA system operational which has its data and keys protected by KMA.

User: the user of a computing platform is an entity interacting with the platform under the platform's security policy. Examples are employees using enterprise-owned hardware. User and administrator might also be identical, e.g., in an end-user environment.

TCG-enabled operating system: the TCG-enabled operating system is the entity that hosts and makes the secured applications run. It includes all platform components required to continue building the chain of trust started by the Core Root of Trust for Measurement: a trusted boot loader (implementing the authenticated boot), the kernel of the Operating System and the initial ramdisk.

3.4 Overview

The use cases are separated into different subsets:

1. Starting the TCG-enabled operating system
2. Creating trusted configuration
3. KMA take ownership
4. Activating KMA
5. Using secured application with KMA

The use cases describe the generic data protection provided by KMA, but the subsets 1 to 4 also apply to applications using directly the TPM keys.

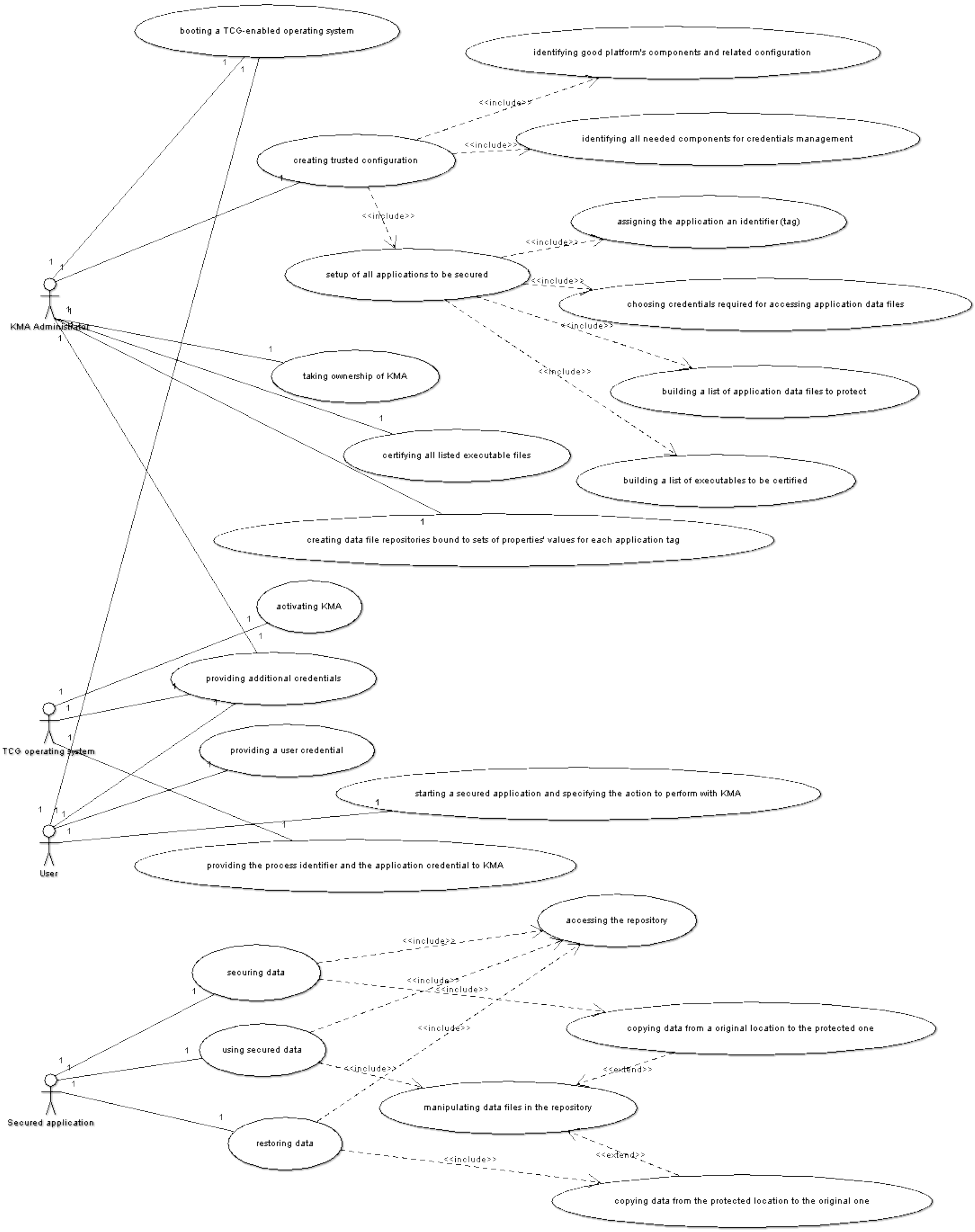

Figure 1: Use cases overview

3.5 Use Cases (Detailed Description)

Each use case focuses on describing how to achieve a single business goal or task. From a traditional software engineering perspective a use case describes just one feature of the system. For most software projects this means that multiple, perhaps dozens, of use cases are needed to fully specify the new system. The degree of formality of a particular software project and the stage of the project will influence the level of detail required in each use case.

A use case defines the interactions between external actors and the system under consideration to accomplish a business goal.

Use cases treat the system as a "black box", and the interactions with the system, including system responses, are perceived as such from outside the system. This is a deliberate policy, because it simplifies the description of requirements, and avoids the trap of making assumptions about how this functionality will be accomplished.

A use case should:

- *describe a business task to serve a business goal*
- *have no implementation-specific language*
- *be at the appropriate level of detail*
- *be short enough to implement by one software developer in a single release.*

3.5.1 Starting the TCG-enabled operating system

Use case unique ID	/UC 10/
Title	Starting the TCG-enabled operating system.
Short description/purpose(s)	The TCG-enabled operating system is measured and started and continues building the chain of trust needed by KMA
Actor(s)	KMA Administrator, User
Preconditions	• KMA components installed.
Postcondition	The TCG-enabled operating system is running and the chain of trust built.
Normal Flow	1. The actor switches the platform on and selects the TCG-enabled operating system to be started.

3.5.2 Creating trusted configuration

Use case unique ID	/UC 20/
Title	Creating trusted configuration.
Short description/purpose(s)	The KMA Administrator evaluates all aspects of the TCG-enabled operating system, in terms of software components, which are critical for KMA to behave as expected and creates the configuration for all applications that will use with KMA.
Actor(s)	KMA Administrator
Includes	• /UC 200/ Identifying good platform's components and related configuration; • /UC 210/ Identifying all needed components for credentials' management; • /UC 220/ Setup of all applications to be secured.
Preconditions	/UC 10/
Postcondition	• All platform's software components are deemed as trusted; • The system components that manage the credentials used for accessing secured applications' data are identified; • The configuration for all secured applications that will use the KMA is set up.
Normal Flow	1. The KMA Administrator evaluates the platform's critical components and, for each, verifies if it is trusted /UC 200/; 2. The KMA Administrator perform the credentials' management setup /UC 210/; 3. The KMA Administrator starts the configuration setup for each application that will use KMA to protect its data: /UC 220/

Use case unique ID	/UC 200/
Title	Identifying trusted platform's components and related configuration.
Short description/purpose(s)	The KMA Administrator looks at the platform components that have been measured by TCG operating system and those which are required for KMA to work properly.
Actor(s)	KMA Administrator
Preconditions	The same as for /UC 20/
Postcondition	The KMA Administrator has checked the list of required platform's components, has verified that the measurements have been taken correctly and that the values are the ones expected.
Normal Flow	1. The KMA Administrator retrieves the list of firmware and software platform's components currently measured by the TCG-enabled operating system; 2. The KMA Administrator includes in such list all software components required for KMA to work properly; 3. The KMA Administrator starts the measurement of each extra component which extends the TPM registers; 4. The KMA Administrator retrieves the values of the TPM registers after doing all measurements; 5. The KMA Administrator verifies if these values are correct by repeating the measurement process of all listed components through a software only procedure.

Use case unique ID	/UC 210/
Title	Identifying all needed components for credentials management.
Short description/purpose(s)	KMA keeps track of all events that cause a change of the value of an application or system property which is related to a credential required to let an application access its protected data. The term “property” refers to an attribute bound to the process of a running application or to the configuration of a system component like a network interface. A subset of the defined properties will be used to grant the access to the protected data repositories. The KMA Administrator defines the components that trustfully report a change of a process's attribute or identifies the components which report themselves a modification of an internal parameter.
Actor(s)	KMA Administrator
Preconditions	The same as for /UC 20/
Postcondition	For each credential used for data access control, a system component has been defined to trustfully report correct information to KMA.
Normal Flow	1. The KMA Administrator verifies the set of credentials usable with the current version of KMA; 2. The KMA Administrator assigns to each credential an existent system component, which will manage the credential and the related application or system property.

Use case unique ID	/UC 220/
Title	Setup of all applications to be secured.
Short description/purpose(s)	The KMA Administrator configures the data protection service for each application to be secured.
Actor(s)	KMA Administrator
Includes	● /UC 2200/ Assigning the application a unique identifier (tag); ● /UC 2210/ Choosing credentials required for accessing application data files; ● /UC 2220/ Building a list of application data files to protect; ● /UC 2230/ Building a list of executables to be certified.
Preconditions	● /UC 210/
Postcondition	The KMA-specific configuration has been supplied for all applications to be secured.
Normal Flow	For each application to be secured: 1. The KMA Administrator assigns a unique identifier to the binary (executable) of the application /UC 2200/; 2. The KMA Administrator chooses the credentials required for the application when it accesses its data files /UC 2210/; 3. The KMA Administrator created a list of data files to protect /UC 2220/; 4. The KMA Administrator creates a list of executable files to be certified /UC 2230/.

Use case unique ID	/UC 2200/
Title	Assigning the application an identifier (tag).
Short description/purpose(s)	The KMA Administrator defines a unique application identifier (tag) to be applied to the main executable binary of an application.
Actor(s)	KMA Administrator
Preconditions	The same as for /UC 220/
Postconditions	The application has been assigned a unique identifier (tag).
Normal Flow	1. The Administrator chooses a tag not assigned to other applications; 1. The Administrator applies the tag to the main executable binary.

Use case unique ID	/UC 2210/
Title	Choosing credentials required for accessing application's data files.
Short description/purpose(s)	From the credentials' set selected in /UC 210/, the KMA Administrator chooses a subset (suitable for the application) which KMA will have to rely upon to enforce access control for the data repositories assigned to the application (identified by tag). Since the credentials can be provided (and subsequently verified) at any time before the application actually accesses a repository, a mechanism must be in place to let KMA perform the credential verification. Each credential (directly or indirectly) corresponds to (or coincides with) a property assumed by the system or by the application when running as process; from KMA point of view, checking the values of all properties associated to the chosen subset of credentials is equivalent to verifying the credentials. Since the main application binary is "tagged", the properties corresponding to the chosen subset of credentials are also bound to the tag.
Actor(s)	KMA Administrator
Preconditions	/UC 2200/
Postconditions	A (sub)set of credentials for the application to access its data repositories is chosen.
Normal Flow	1. The Administrator chooses a subset of credentials from the set defined in /UC 210/; 2. The Administrator binds the application tag with the chosen subset.

Use case unique ID	/UC 2220/
Title	Building a list of application data files to protect.
Short description/purpose(s)	The KMA Administrator creates the list of data files to be protected for the application.
Actor(s)	KMA Administrator
Preconditions	/UC 2210/
Postconditions	The list of data files to protect is created for each application.
Normal Flow	1. The KMA Administrator creates the list of data files that will be protected by KMA for the application.

Use case unique ID	/UC 2230/
Title	Building the list of executable files to be certified for the application.
Short description/purpose(s)	The KMA Administrator creates a list of the executable files that will be certified. This procedure is required because only certified binaries can interact with KMA and because it assures the integrity of the application's binaries.
Actor(s)	KMA Administrator
Preconditions	• /UC 2210/
Postcondition	The list of executables to be certified for the application is created.
Normal Flow	1. The KMA Administrator add to such list for each application: • the main executable file of the application and the shared libraries it depends on; • the executable file (and the shared libraries it depends on) of all components managing the set of credentials required for the application to access the protected data and chosen in /UC 2210/.

3.5.3 KMA take ownership

Use case unique ID	/UC 30/
Title	Taking ownership of KMA.
Short description/purpose(s)	The KMA Administrator takes the ownership of the KMA; this operation: ● guarantees that the existence of the current (chosen) system configuration is a required condition for KMA to be activated and to work properly; ● causes the setting of a secret subsequently needed by KMA Administrator to certify all binaries.
Actor(s)	KMA Administrator
Preconditions	● /UC 20/ ● After /UC 20/ is completed, the TCG operating system must be restarted (/UC 10/)
Postcondition	● The platform configuration required to let KMA be fully operational is set; ● The KMA Administrator's password for certifying binaries is set.
Normal Flow	1. The KMA Administrator starts the KMA taking ownership procedure 2. The KMA administrator is requested to choose a password required for activating the certification process at a later stage; 3. The activation of KMA is linked to the current system configuration.

NOTE

Whilst the interaction with the TPM has not been modelled in the use cases description:

- the step n. 2 of the normal flow refers to the creation of a certification key protected by means of a TPM binding key, whose authorization secret is derived from the password chosen by the KMA Administrator;
- the step n. 3 of the normal flow refers to the TPM sealing of the certification key created during step n. 3 against the current configuration (i.e. set of PCR values).

The interaction with the TPM has been modelled, instead, in the use cases implementation described in the next sections.

Use case unique ID	/UC 40/
Title	Certifying listed executable files.
Short description/purpose(s)	The Administrator certifies each executable file present in the lists created in UC 2230 for each application.
Actor(s)	KMA Administrator
Preconditions	● /UC 30/ ● After /UC 30/ being completed, the TCG operating system must be restarted (/UC 10/)
Postcondition	All executable files in the lists previously created have been certified.
Normal Flow	1. The KMA Administrator checks each executable to certify sign binary by comparing it (or its hash) with corresponding from a “trusted” source to decide if a binary can be considered genuine and trustworthy; 2. All binaries are verified and all are genuine; 3. The KMA Administrator starts the “certify” function giving the required secret (set in /UC 30/); 4. Each executable is certified; for the main executables of the applications to be secured, the tag is also applied.
Alternative Flow	1. The KMA Administrator checks each executable to certify sign binary by comparing it (or its hash) with corresponding from a “trusted” source to decide if a binary can be considered genuine and trustworthy; 2. All binaries are verified and some file are not genuine; 3. The KMA Administrator executes the “certify” function giving the secret required, only for the genuine binaries. 4. Each genuine executable is certified; for the main executables of the applications to be secured, the tag is also applied.

Use case unique ID	/UC 50/
Title	Creating data file repositories bound to sets of properties' values for each application tag.
Short description/purpose(s)	For each application (i.e. for each tag defined), the KMA Administrator creates a set of protected (i.e. encrypted) data repositories. Because each tag is bound to a set of application's or system's properties, first the Administrator checks all the possible values for each property, then creates one data repository bound to each desired collection of values. KMA will therefore grant the access to one application's repository only if, at the access time, all properties' values match one of the wanted collection.
Actor(s)	KMA Administrator
Preconditions	• /UC 220/
Postcondition	The protected data repositories for each application tag are created.
Normal Flow	For each application tag, the KMA administrator: 1. retrieves the set of associated properties; 2. selects all desired values for each property 3. creates a new data repository for each wanted collection of properties values for the selected tag; 4. binds the new data repository to the related collection of values.

NOTE

To achieve some security objectives stated in the next section, this use case may be implemented using encryption for the protected repositories; in this case an encryption key must be generated bound to each collection of properties' values. KMA must protect such encryption key an a way that the security goals for KMA can be met. This key must be available to KMA when the application wants to access its data under certain application and system properties' values (as described in /UC B0/, /UC C0/ and /UC D0/). A possible implementation of the mechanisms for generating and retrieving the keys bound to the collection of properties' values is described in the use case implementation section.

3.5.4 Activating KMA

Use case unique ID	/UC 60/
Title	Activating KMA
Short description/purpose(s)	The TCG-enabled operating system activates the KMA software.
Actor(s)	TCG-enabled operating system
Preconditions	• /UC 40/ • /UC 50/ • After /UC 40/ and /UC 50/ being completed, the TCG operating system must be restarted (/UC 10/)
Postcondition	The KMA software is fully operational: • the measurements of all components required by KMA to work properly are correctly taken by the TCG-enabled operating system; • the KMA has successfully performed a TPM operation that proves that the current measurements matches those taken by the KMA Administrator in the use case /UC 30/.
Normal Flow	1. The TCG-enabled operating system performs the measurements of the platform components defined by the KMA Administrator; 2. The KMA perform a TPM operation (unsealing) to verify the current configuration; 3. The result is “success”, i.e. the current configuration matches the one previously chosen by the KMA Administrator; 4. KMA is fully operational.
Alternative Flow	1. The TCG-enabled operating system performs the measurements of the platform components defined by the KMA Administrator; 2. The KMA perform a TPM operation (unsealing) to verify the current configuration; 3. The result is “failure”, i.e. the current configuration does not match the one previously chosen

Use case unique ID	/UC 60/
	by the KMA Administrator; 4. KMA is not operational.

Use case unique ID	/UC 70/
Title	Providing additional credentials
Short description/purpose(s)	The actor provides additional credentials (among those chosen by the KMA Administrator).
Actor(s)	KMA Administrator, User, TCG-enabled operating system.
Preconditions	• /UC 40/ Normal flow • /UC 60/ Normal flow
Postcondition	KMA received an update of a system property property value.
Normal Flow	1. The actor interacts with the system component bound to a credential, as defined by KMA Administrator; 2. KMA verifies that the component designated to trustfully report this information is certified and it is not corrupted; 3. A system property has just been set for the first time or its value has been modified; 4. The updated property value is reported to KMA.
Alternative Flow	1. The actor interacts with the system component bound to a credential, as defined by KMA Administrator; 2. KMA verifies that the component designated to trustfully report this information is not certified or it is corrupted; 3. A system property has just been set for the first time or its value has been modified; 5. The updated property value is not reported to KMA.

NOTES

The additional credential that may be required to let the access of an application to its repository be bound to (or can be itself) a system property (i.e. not an application property). In the use cases description, only one option is considered: unless the component managing the property value is part of the core of the TCG operating system (i.e. the kernel) - in which case (not modelled in the use case descriptions) its integrity is implicitly verified when KMA is activated (/UC 60/) - KMA explicitly verifies the component integrity when it is loaded, i.e. the first time it sets the system property.

Use case unique ID	/UC 80/
Title	Providing a user credential
Short description/purpose(s)	The User provides his credential to KMA, when logging in to the TCG-enabled operating system.
Actor(s)	User
Preconditions	• /UC 40/ Normal flow • /UC 60/ Normal flow
Postcondition	The property value representing a user currently logged in to the system has been reported to KMA.
Normal Flow	1. The User logs in to the TCG-enabled operating system using the configured authentication method; 2. The component managing the user credential and the related property is activated; KMA verifies that it is certified and it is not corrupted; 3. The property value bound to the user credential for the User logged in is reported to KMA.
Alternative Flow	1. The User logs in to the TCG-enabled operating system using the configured authentication method; 2. The component managing the user credential and the related property is activated; KMA verifies that is not certified or it is corrupted; 3. The property value bound to the user credential for the User logged in is not reported to KMA.
Alternative Flow	1. The User logs in to the TCG-enabled operating system using the configured authentication method; 2. No component was defined by KMA Administrator to manage the user credential; 3. The property value bound to the user credential for the User logged in is not reported to KMA.

NOTE

For Unix-like operating systems, the property bound to the user credential is the `uid`: this is the property of the established user session after login and will be inherited by all applications launched within this session. The user credential is the one the User must present to log in to the TCG-enabled operating system according to the configured authentication method; therefore a weak authentication method (or a weak credential) for the user will result in a weak access control for application protected repositories, with respect to the user credential.

Use case unique ID	/UC 90/
Title	Starting a secured application and specifying the action to perform with KMA.
Short description/purpose(s)	The User starts a secured application, specifying the action KMA must to perform for it. The action can be securing unprotected data, using secured data and restoring data to the unprotected state.
Actor(s)	User
Preconditions	/UC 10/ /UC 60/
Postcondition	The result of the integrity check on the application's executable binary file is sent to KMA.
Normal Flow	1. The User launches the application and specifies the action that will be performed by KMA; 2. The TCG-enabled operating system receives the User request; 3. The TCG-enabled operating system creates a new process for the launched application; 4. The TCG-enabled operating system executes /UC A0/

Use case unique ID	/UC A0/
Title	Providing the process identifier and the application credential to KMA.
Short description/purpose(s)	The TCG-enabled operating system sends KMA the information needed to perform the operation requested by the User.
Actor(s)	TCG-enabled operating system.
Preconditions	/UC 90/
Postcondition	The application credential (tag) and the process identifier (which is the property bound to the application credential) of the application being started are sent to KMA by TCG-enabled operating system.
Normal Flow	1. The TCG-enabled operating system requests KMA to verify the application integrity: it is certified and not corrupted. 2. The TCG-enabled operating system reports to KMA: ● the process identifier; ● the application credential (tag); ● the action requested by the User.
Alternative Flow	1. The TCG-enabled operating system requests KMA to verify the application integrity: it is not certified and it is corrupted. 2. The TCG-enabled operating system does not report any information to KMA.

3.5.5 Using secured application with KMA

Use case unique ID	/UC B0/
Title	Securing data.
Short description/purpose(s)	The secured application requests the KMA to protects its data files
Actor(s)	Secured application
Includes	• /UC B00/ • /UC B10/
Preconditions	• /UC 60/ Normal flow • /UC 70/ Normal flow • /UC 80/ Normal flow • /UC A0/ Normal flow
Postcondition	The data files for the secured application have been protected by KMA.
Normal Flow	1. The secured application requests KMA to access its protected repository (bound to the properties' values currently in force) /UC B00/; 2. The secured application requests the KMA to move its data files from the original unprotected location to the protected repository /UC B10/;

Use case unique ID	/UC B00/
Title	Accessing the repository.
Short description/purpose(s)	A secured application requests KMA to access the properly secured data repository. KMA verifies if the application is tagged and if a repository exists that is bound to the combination of the current values for the set of properties associated to the tag: if yes, the KMA grants the secured application access to that repository.
Actor(s)	Secured application.
Preconditions	The same as for /UC B0/
Postcondition	The User uses the secured application and only the latter is allowed to retrieve and manipulate its data files.
Normal Flow	1. The secured application requests to access the repository to KMA; 2. KMA identifies the application by its process identifier; 3. KMA verifies that the application is tagged (there exists a tag associated to the process identifier); 4. KMA retrieves the set of (application and, optionally, system) properties associated to the application tag; 5. Using the process identifier, KMA requests to the TCG-enabled operating system the current values for the application properties (like the one bound to the user credential) and checks that such values have been previously recorded (in /UC 70/ and /UC 80/); 6. KMA collects the recorded properties' values for the requesting application and for the system; 7. KMA verifies if there exists a repository created by KMA Administrator bound to the collection of properties' values; 8. KMA grants the secured application access to the matched repository.

Use case unique ID	/UC B00/
Alternative Flow	1. The secured application requests to access the repository to KMA; 2. KMA identifies the application by its process identifier; 3. KMA verifies that the requesting application is not tagged (i.e. /UC A0/ previously failed); 4. The requesting application is not a secured application and the procedure fails.
Alternative Flow	1. The secured application requests to access the repository to KMA; 2. KMA identifies the application by its process identifier; 3. KMA verifies that the application is tagged (there exists a tag associated to the process identifier); 4. KMA retrieves the set of (application and, optionally, system) properties associated to the application tag; 5. Using the process identifier, KMA requests to the TCG-enabled operating system the current values for the application properties (like the one bound the user credential) and checks that some of such values have not been previously recorded (i.e. /UC 70/ or /UC 80/ failed); 6. The procedure fails.
Alternative Flow	1. The secured application requests to access the repository to KMA; 2. KMA identifies the application by its process identifier; 3. KMA verifies that the application is tagged (there exists a tag associated to the process identifier); 4. KMA retrieves the set of (application and, optionally, system) properties associated to the application tag; 5. Using the process identifier, KMA requests to the TCG-enabled operating system the current values for the application

Use case unique ID	/UC B00/
	properties (like the one bound the user credential) and checks if such values have been previously recorded; 6. KMA collects the recorded properties' values for the requesting application and for the system; 7. None of repositories is bound to the collection of the properties' values; 8. The procedure fails.

Use case unique ID	/UC B10/
Title	Copying data from the original location to the protected one.
Short description/purpose(s)	The secured application retrieves from KMA the list of files to be protected and copies the files from their original unprotected location to the protected repository previously accessed.
Actor(s)	Secured application.
Extends	/UC C00/
Preconditions	● The same as for /UC C00/ ● /UC B10/
Postcondition	The data files of the secured application in the list defined by KMA Administrator in /UC 2220/ have been moved from their original unprotected location to the KMA protected repository.
Normal Flow	Through a KMA module loaded in its memory space: 1. The secured application retrieves the list of files to protect (i.e. to move to the protected repository), defined by the KMA Administrator; 2. The secured application copies the data files from from their original location to the protected repository accessed in /UC B00/; 3. The secured application removes each file from the original location.

NOTE

To let the secured application run unmodified; the KMA module takes control once the application is loaded in memory but before the application code is actually executed. Once the control is passed back to the application code, the application runs as usual searching for files in their original location, without any knowledge of the protected repository. If the latter is provided as mounted file system, to let application access its data files, during step n. 3 it is necessary to replace the original files with links (e.g. symbolic links for Unix-like operating systems) to the corresponding files stored in the protected repository.

Use case unique ID	/UC C0/
Title	Using secured data.
Short description/purpose(s)	The secured application requests the KMA to use its data files previously protected.
Actor(s)	Secured application.
Includes	• /UC B00/ • /UC C00/
Preconditions	• /UC 70/ Normal flow • /UC 80/ Normal flow • /UC A0/ Normal flow
Postcondition	The secured application is running as usual, using (reading, writing) the data files protected in the repository.
Normal Flow	1. The secured application requests the KMA to access its protected repository /UC B00/; 2. The secured application starts manipulating (reading, writing) its data files stored in the protected repository /UC C00/.

Use case unique ID	/UC C00/
Title	Manipulating data files in the repository.
Short description/purpose(s)	The secured application requests the KMA to perform an input/output operation (reading, writing) in files stored on its protected repository.
Actor(s)	Secured application.
Preconditions	/UC B00/
Postcondition	The secured application has manipulated its protected data files.
Normal Flow	1. The secured application runs performing the usual tasks by managing data files in the protected repository.

Use case unique ID	/UC D0/
Title	Restoring data.
Short description/purpose(s)	The secured application requests the KMA to restore the application's data files from the protected repository to their original location.
Actor(s)	Secured application.
Includes	• /UC B00/ • /UC D00/
Preconditions	• /UC 60/ Normal flow • /UC 70/ Normal flow • /UC 80/ Normal flow • /UC A0/ Normal flow • /UC C0/
Postcondition	The data files for the secured application have been restored to their original unprotected location.
Normal Flow	1. The secured application requests KMA to access its protected repository (bound to the properties' values currently in force) /UC B00/; 2. The secured application requests the KMA to move its data files from the protected repository to their original unprotected location /UC D00/;

Use case unique ID	/UC D00/
Title	Copying data from the protected location to the original one.
Short description/purpose(s)	The secured application retrieves from KMA the list of files to be protected and copies the files from the protected repository previously accessed to their original unprotected location.
Actor(s)	Secured application
Extends ●	/UC C00/
Preconditions	● The same as for /UC C00/ ● /UC 2220/ ● /UC B0/
Postcondition	The data files of the secured application in the list defined by KMA Administrator in /UC 2220/ have been moved from the KMA protected repository to their original unprotected location.
Normal Flow	Through a KMA module loaded in its memory space: 1. The secured application retrieves the list of files to protect (i.e. to move to the protected repository), defined by the KMA Administrator; 2. The secured application copies the data files from the protected repository accessed in /UC B00/ to their original unprotected location; 3. The secured application removes each file from the protected repository.

4 Security Objectives & Security Requirements

4.1 Security Objectives

The security objectives shall address all of the security environment aspects identified. The security objectives shall reflect the stated intent and shall be suitable to counter all identified threats and cover all identified organizational security policies and assumptions. A threat may be countered by one or more objectives for the product, one or more objectives for the environment, or a combination of these.

/SO 10/ Data isolation at run-time

Isolation between protected data of different applications/services at run-time must be guaranteed to prevent that, if an application gets compromised (e.g. because of a flaw) and the protected data can be accessed in memory by an attacker, the protected data of all other applications/services can be accessed by the attacker.

/SO 20/ No unauthorized use of TOE components

Unauthorized entities must not be able to arbitrarily execute TOE components.

/SO 30/ No off-line access to protected data

Unauthorized entities must not be able to access the protected data by directly accessing the storage device from another platform (this is not considered in this document a hardware attack).

/SO 40/ No unauthorized access to protected data

Unauthorized entities (e.g. applications, users, etc.) must not be able to access the protected data.

/SO 50/ No access to protected data with TCB integrity compromised

Unauthorized entities must not be able to access the protected data if the platform is started with a different TCB configuration or a different TCB.

/SO 60/ No access to protected data with TOE integrity compromised

Unauthorized entities must not be able to access the protected data when starting the platform with a different TOE configuration or different versions of the TOE components.

4.2 Security Requirements

This part of the requirement specification defines the security requirements that have to be satisfied by the product. The statements shall define the functional and assurance security requirements that the product and the supporting evidence for its evaluation need to satisfy in order to meet the security *objectives.*

/SR 10/ Integrity of the TCB

The TCB should be protected from manipulations to guarantee the enforcement of data protection.

/SR 20/ Integrity of the TOE

The TOE should be protected from manipulations to guarantee the enforcement of data protection.

/SR 30/ Confidentiality and integrity of application/data

This requirement should hold during execution and storage.

/SR 40/ Trusted path to user binding to (system and application) properties

The inputs/outputs of the application a user interacts with should be protected from unauthorized access by other applications.

5 Supplementary Requirements

Obligatory criteria, mandatory for successful completion.

5.1 Preconditions

Requirements that have to be fulfilled already, because they were needed for the development process.

/PR 10/ Trusted Bootloader

A Bootloader with TPM-support is required.

/PR 20/ TPM driver

A TPM driver for TPM version 1.2 is required.

/PR 30/ TCG Software Stack (TSS)

An implementation of TCG Software Stack (TSS) is required.

5.2 Required Criteria

Mandatory criteria, that are obligatory for successful completion.

/RC 10/ Single property support for data access control

The realization of the use cases should support a single application property (user currently logged in) for access control of protected data.

/RC 20/ Single Linux distribution support

The realization of the use cases should be based on a Linux architecture with support for a single distribution.

/RC 30/ Password change

Administrator can change the passphrase used for TOE administration.

/RC 40/ TPM support

The product should support a TPM of version 1.2 (or higher) to protect the product's integrity. (Refer to appropriate security requirements or security objectives).

/RC 50/ Updates for applications/services not required for protected storage

The TOE must provide a generic protection mechanism for data files that does not require any modification to the application/service at build time.

/RC 60/ Minimal updates for applications/services directly using TPM keys

The TOE must provide support for the access to TPM keys bound to system/application integrity and properties, requiring minimal modifications at build time for application directly using the TPM keys.

/RC 70/ TPM support

The TOE must provide support for seamless upgrade of the operating system and the protected applications.

5.3 Desired Criteria

Optional criteria, that are not mandatory for successful completion.

/DC 10/ Multiple properties support for data access control

The realization of the use cases should support multiple application and system properties for access control of protected data.

/DC 20/ Multiple Linux distributions support

The realization of the use cases should be based on a Linux architecture with support for multiple distributions.

/DC 30/ Xen support

The realization of the use cases should be based on a virtualized Linux instances based on the Xen architecture.

5.4 Distinguishing Criteria

What our product does not provide.

5.5 Execution Environment

This section specifies software and hardware the user requires at least to run our product successfully.

5.5.1 Software

- Standard Linux 2.6.x distribution (OpenSUSE 10.x)
- (optional) Xenolinux 3.x.y (Linux 2.6.x running on top of Xen 3.x.y hypervisor)

5.5.2 Hardware

- Intel or AMD Platform
- TPM 1.2 Platform

5.6 Development Environment

This section specifies hard- and software that developers need at least to implement the product successfully.

5.6.1 Software

- Standard Linux 2.6.x distribution (OpenSUSE 10.x)
- gcc 4.x.y
- (optional) Xenolinux 3.x.y (Linux 2.6.x running on top of Xen 3.x.y hypervisor)

5.6.2 Hardware

- Intel or AMD Platform
- TPM 1.2 Platform

6 High-Level Software Architecture

6.1 Introduction

This section contains the views of a high-level software architecture for KMA service. In particular the granularity of the views is at component level: components combining to bring about the realisation of the same functional requirement are grouped by packages.

To model the components and their interactions class and sequence diagrams have been used. However, to reduce the complexity of the diagrams some informal variations have been applied: e.g. data types are not actually representing the real types for class diagrams and loops and branches have been represented in a simple manner in the sequence diagrams. Moreover, the diagrams do not model all aspects and some existing components which are modelled do not follow the object-oriented paradigm.

For all these reasons, the diagrams presented in this section are not intended to be a (complete) specification for the actual design and they cannot be used to implement the components using software engineering tools. Whilst the diagrams describe the intended behaviour of the components, the detailed design of the real implementations may considerably deviate from the diagrams; therefore the latter have to be considered as informative.

6.2 Logical view

6.2.1 Packages

6.2.1.1 KMA bootstrap manager

This package is used during the setup of the trusted configuration and it is responsible for KMA activation during the bootstrap process of the TCG-enabled operating system. This package includes some components that should run in kernel memory space and others that should run in the user memory space.

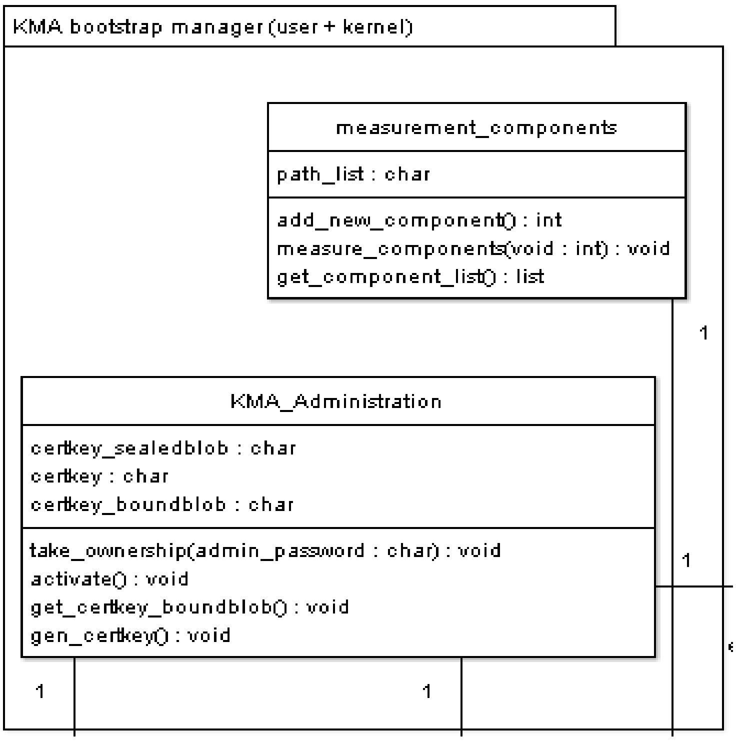

Figure 2: KMA bootstrap manager package

6.2.1.2 TPM interface

This package is responsible for mediating all accesses to the TPM.

The TPM keys are not modelled in this section but are needed for real implementations of bind/unbind and seal/unseal operations. The Storage Root Key (SRK) is not modelled either.

This package includes some components that should run in kernel memory space (e.g. the TPM driver) and others that should run in user memory space (e.g. the TSS stack). The unsealing operation performed during the KMA activation, must be done in kernel space (part of the TCB) in order to prevent the unsealed certification key leaving TCB. The same applies for decryption when the chosen storage cipher method is not “direct” but “TPM” in order to prevent the storage encryption key leaving TCB

The direct use of TPM keys by applications for protecting their data (instead of using the storage service provided by KMA) is not modelled neither in the use cases description nor in their implementation, but the design described in the use cases implementation can easily support this approach. This could be implemented using the TSS in user memory space and authorisation call-back functions which should call functions in kernel space implemented by a “ticket manager” component (not presented nor discussed in this document) responsible for calculating intermediate digests required by TPM authentication protocols (according to the TSS and TPM specifications) from the tokens held by the property manager.

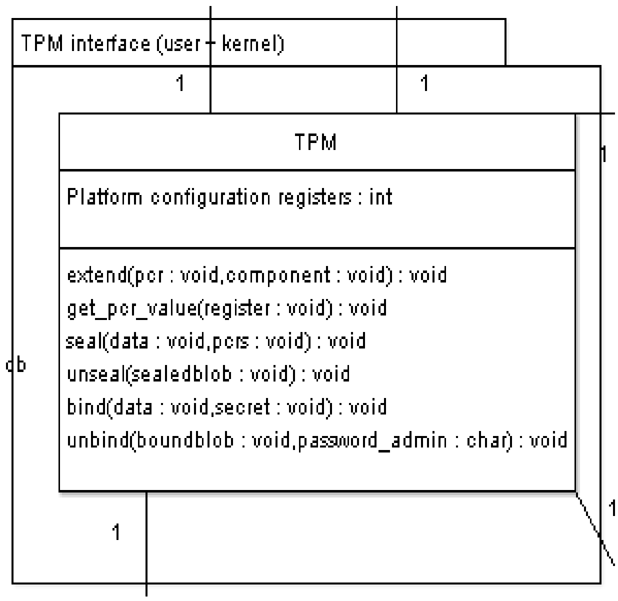

Figure 3: TPM interface package

6.2.1.3 Certify service

This package is responsible for certifying the binaries of the secured applications, of all applications managing credentials and of the shared libraries both depend on.

This package includes components that should run in the user memory space; however the certify operation must be performed in a controlled environment by KMA Administrator. The configuration at the bootstrap of TCG-enabled operating system is checked by KMA activation procedure which fails if the configuration is not correct. However the KMA Administrator must check that such configuration is still in place i.e. that that malicious applications that could fool KMA administrator are not running in user memory space. To achieve this goal the certify operation should be executed soon after the completion of the bootstrap, upon successful activation of KMA.

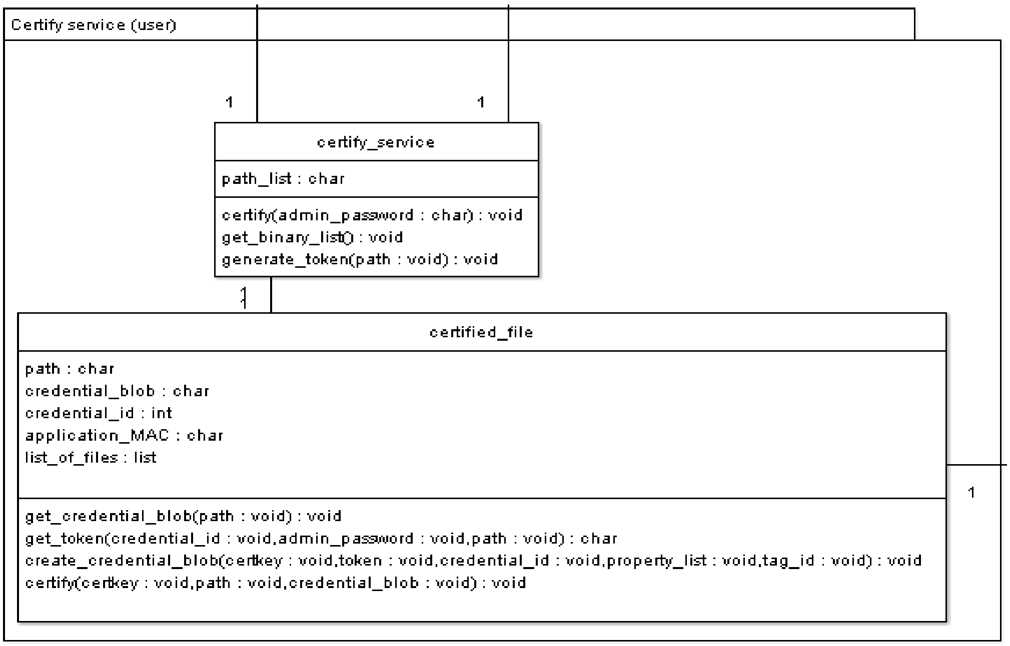

Figure 4: certify service package

6.2.1.4 Storage service

This package is responsible for the management of all operations related to the protected storage.

This package includes components that should run in the user memory space; however the security-critical operations like encryption/decryption are performed in kernel memory space by a different package (data encryption service).

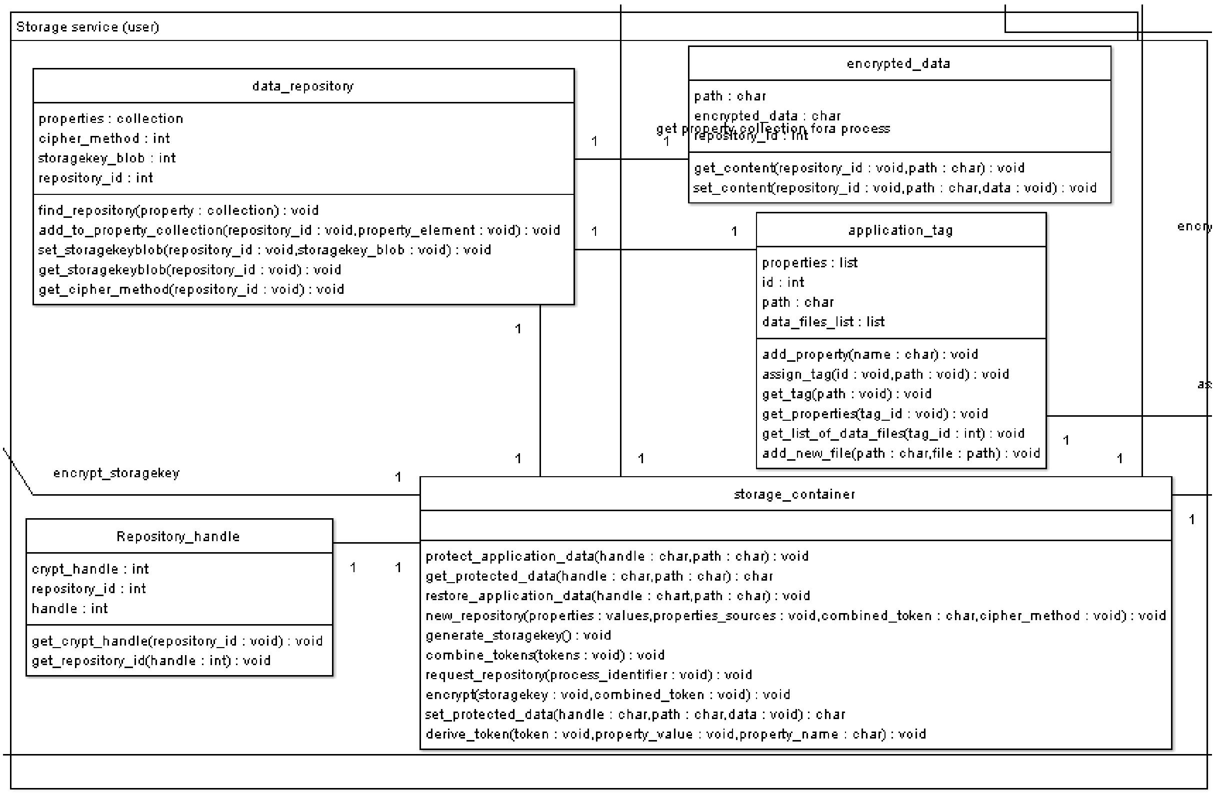

Figure 5: storage service package

6.2.1.5 TCG-enabled operating system

This package represents the Operating System enabled to build the chain of trust. It hosts all KMA components and the secured application: whilst in the use case descriptions it is considered as a whole, for the purposes of the use cases implementation, this package only represents the running base OS while all other components are modelled in other packages.

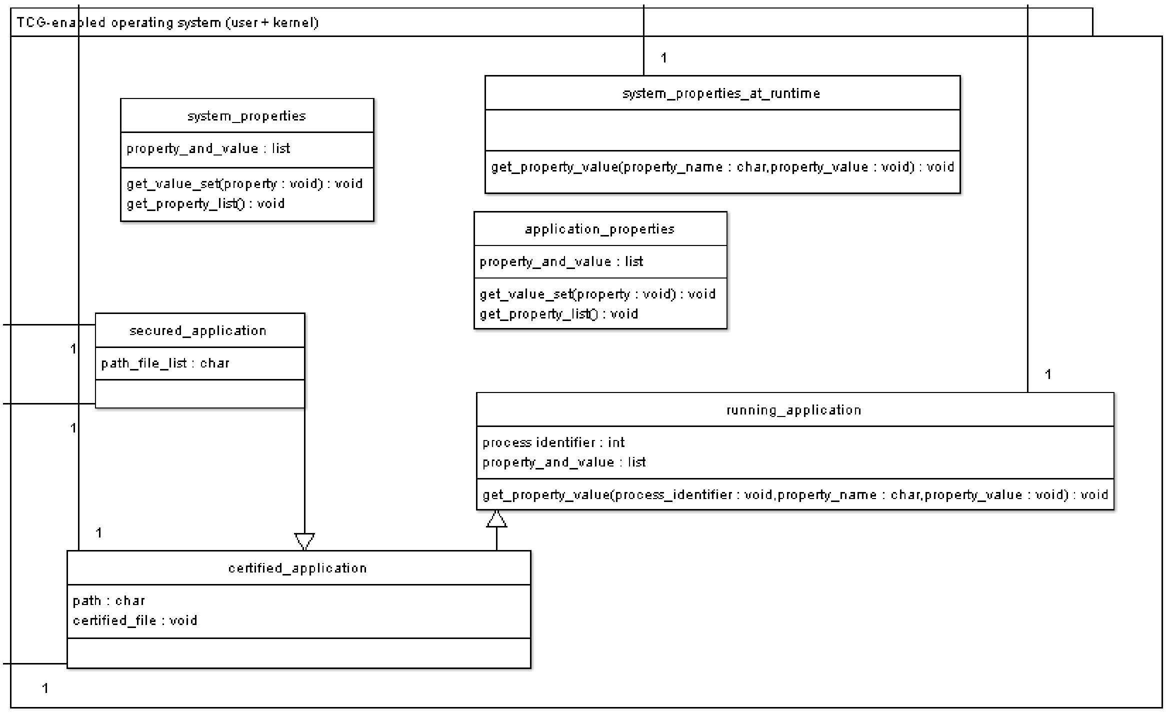

Figure 6: TCG-enabled operating system package

6.2.1.6 Property manager

This package is responsible for collecting all required sensitive data, namely property values of the running system and applications and the tokens used, directly or indirectly via TPM, for encryption/decryption of the storage keys.

This package includes components that should run in the kernel memory space only.

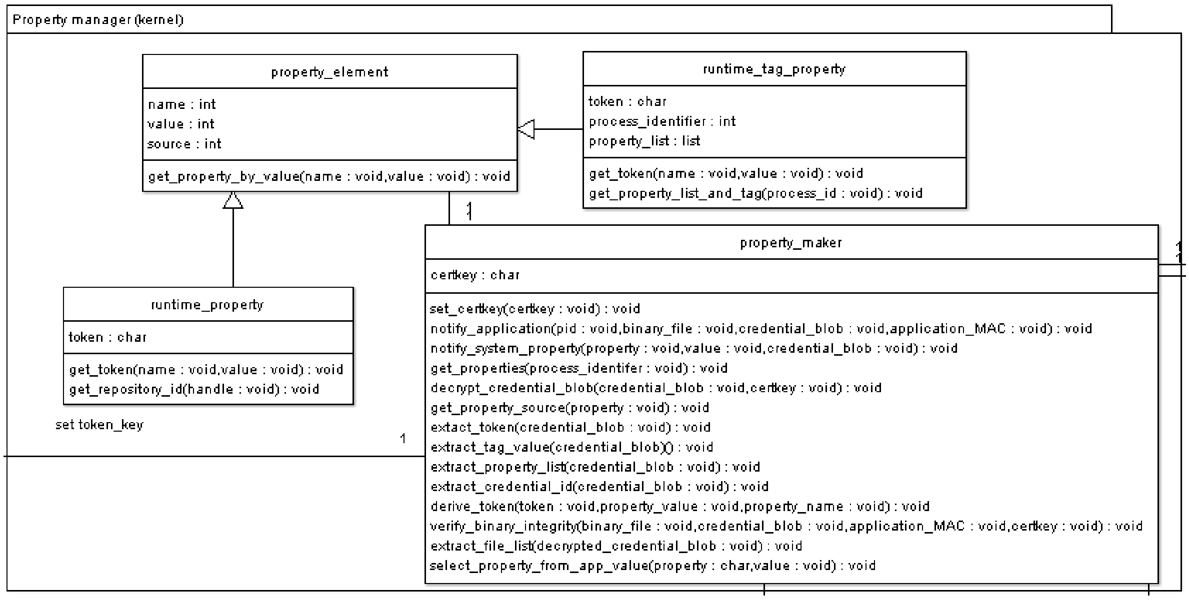

Figure 7: property manager package

6.2.1.7 Data encryption service

This package is responsible for encrypting and decrypting data stored on the protected repository. It holds the storage encryption key in clear text once the conditions (i.e. certain properties' values) required for the application to access its data are met.

This package includes components that should run in the kernel memory space only.

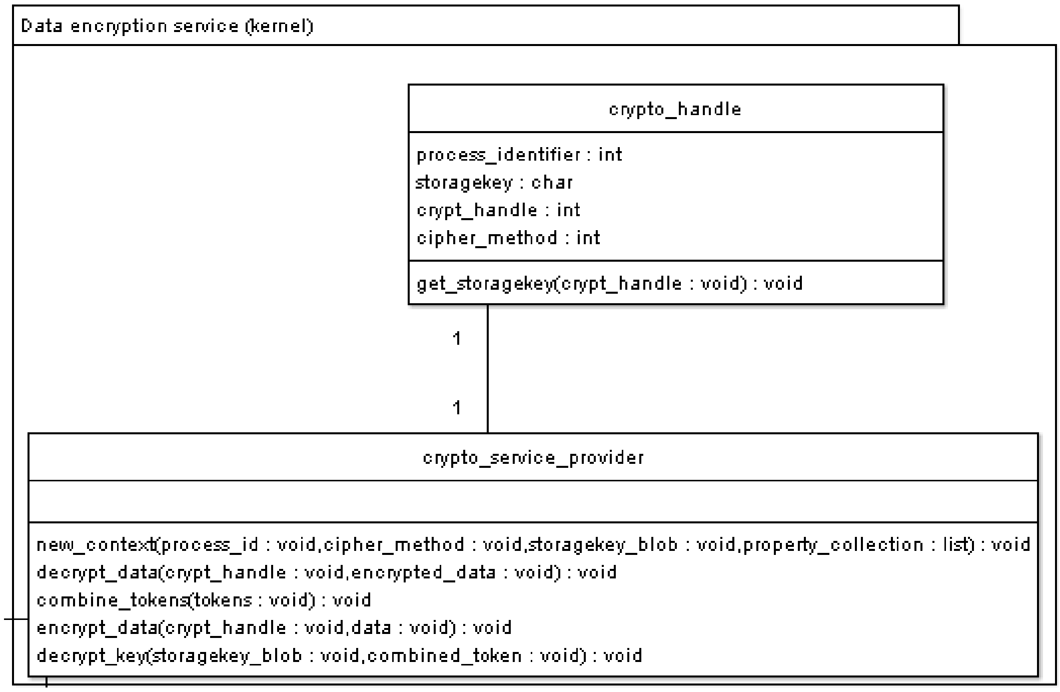

Figure 8: data encryption service package

6.2.2 Use case realisation

Table 1 lists the required packages for the realisation of each use case. The realisation of the use cases /UC 220/, /UC A0/, /UC C00/ and /UC D00/ is not reported here in this section because they include or are included in other use cases. Then a possible implementation of such use cases is described through the interaction of the components (grouped by packages) represented in sequence diagrams.

Use Case	Required packages
UC 10	TCG-enabled operating system
UC 200	KMA bootstrap manager, TPM interface
UC 210	Certify service
UC 2200	Storage service
UC 2210	Storage service, TCG-enabled operating system
UC 2220	Storage service
UC 2230	Certify service, storage service
UC 30	KMA bootstrap manager, TPM interface
UC 40	KMA bootstrap manager, TPM interface, certify service, storage service
UC 50	Storage service, TCG-enabled operating system, TPM interface, certify service, property manager
UC 60	KMA bootstrap manager, TPM interface, property manager
UC 70	TCG-enabled operating system, property manager
UC 80	TCG-enabled operating system, property manager
UC A0	TCG-enabled operating system, property manager
UC B0	Storage service, data encryption service
UC C0	Storage service, data encryption service
UC D0	Storage service, data encryption service
UC B00	TCG-enabled operating system, property manager, storage service, data encryption service, TPM interface

Table 1: Packages required by use cases

/UC 10/

The actor starts the bootstrap of the `TCG-enabled operating system`.

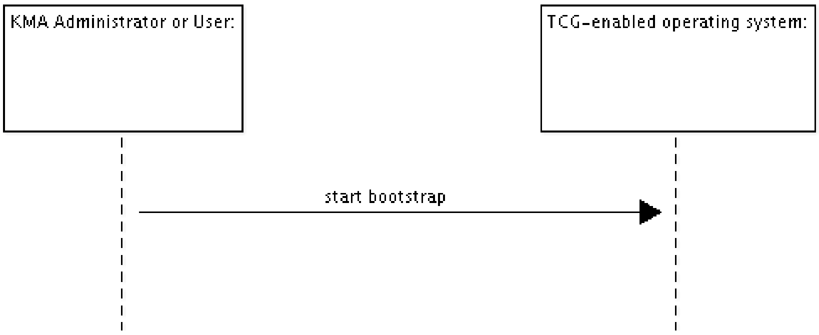

Figure 9: /UC 10/ implementation

/UC 200/

The KMA Administrator calls the `add_new_component(component)` function in order to buid the system components list required for KMA to work propertly.

The the Administrator starts the `measure_components()` which is applied to all selected components and in turn calls `extend(pcr, component)`; then the KMA Administrator evaluates the PCR registers of the TPM device by calling the `get_PCR_value(pcr)`function. The KMA administrator must check the obtained values by measuring again in software the components. The latter procedure is not defined by this use case implementation.

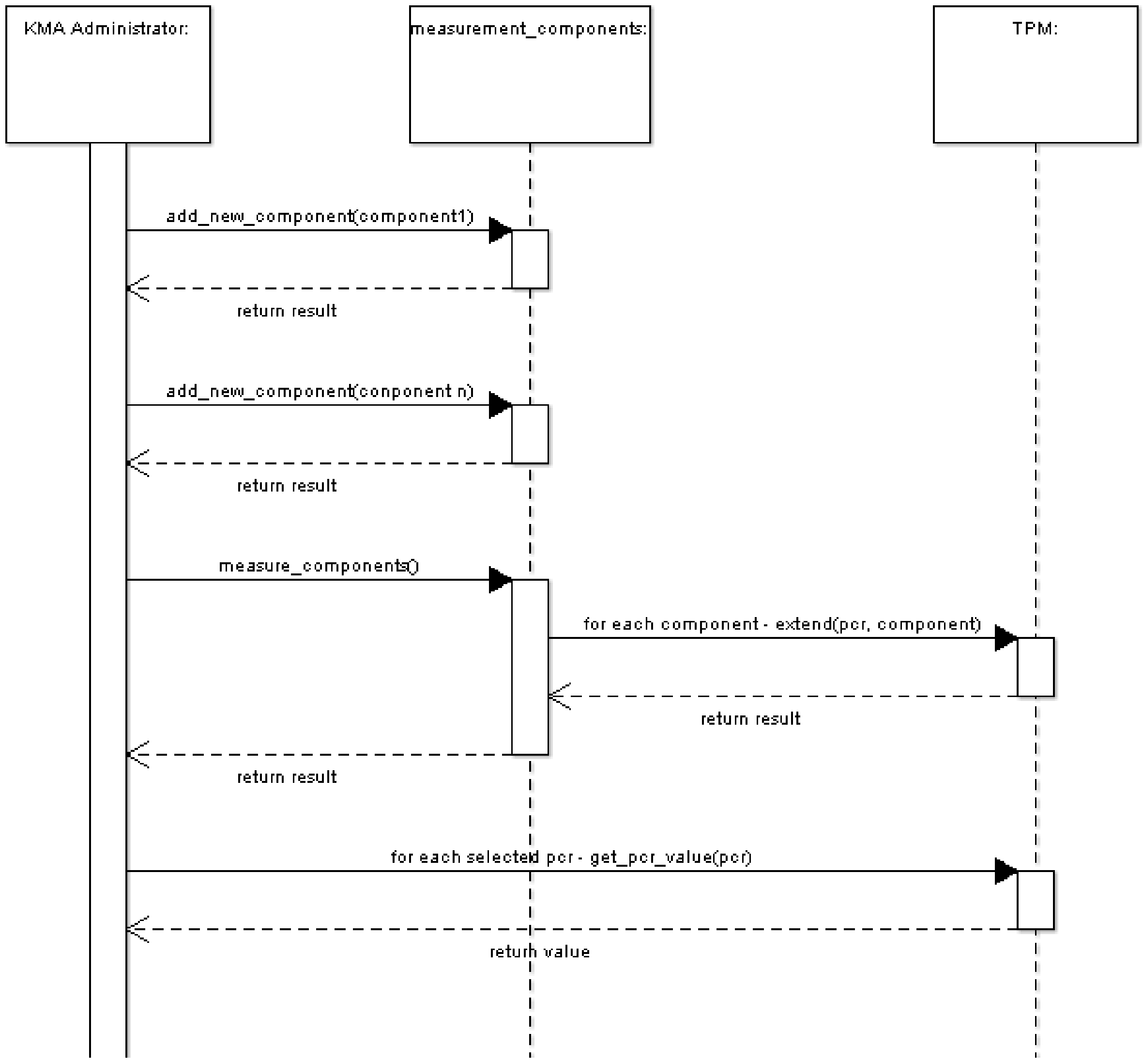

Figure 10: /UC 200/ implementation

/UC 210/

The KMA Administrator identifies the components (i.e. applications) that will be used, when the KMA is running, to manage the credentials and the related properties for the authentication when a protected file is requested.

An application managing credentials can deal with only one property, bound to one credential, chosen between the `application_properties` or the `system_properties`, and requires to be certified for this purpose.

For this purpose, a new instance of the class `certified_file` will be created in order to make the application be certified: the association of the credential (and the relateed property) to application is done by passing `application_path` and `credential_id` to the constructor.

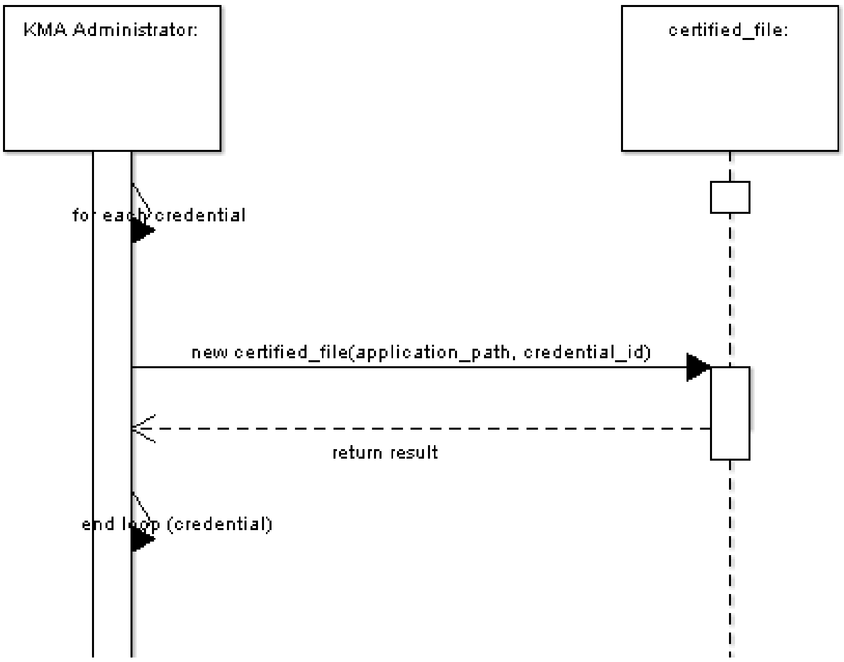

Figure 11: /UC 210/ implementation

/UC 2200/

The KMA Administrator chooses an application to be secured, then creates a unique `tag_id` to be assigned to the binary by calling the function `assign_tag(id, path)` to the `application_tag` class.

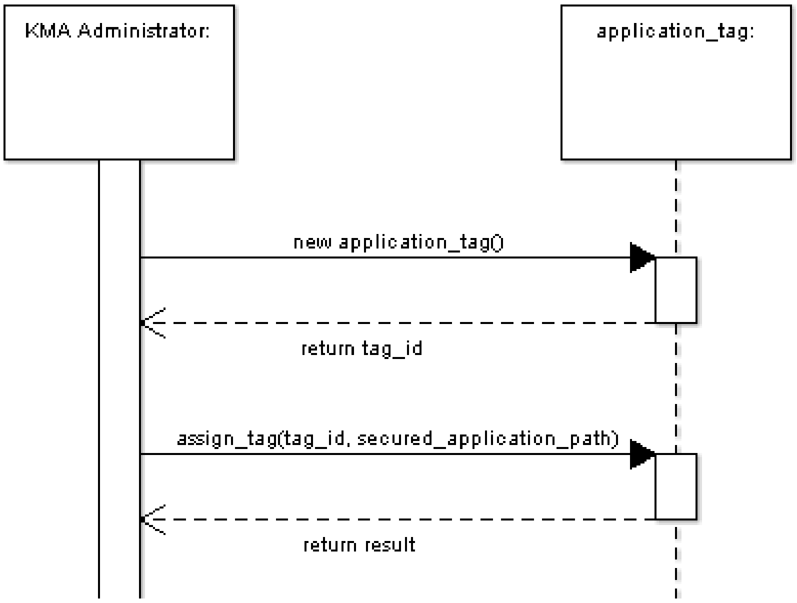

Figure 12: /UC 2200/ implementation

/UC 2210/

The KMA Administrator selects among all managed credentials those required for the secured application (which has been assigned a unique tag in UC 2200) to access its protected files. This results in an association between the `tag id` and a subset of `application_properties` and `system_properties` by calling the function `add_property(id, property)`.

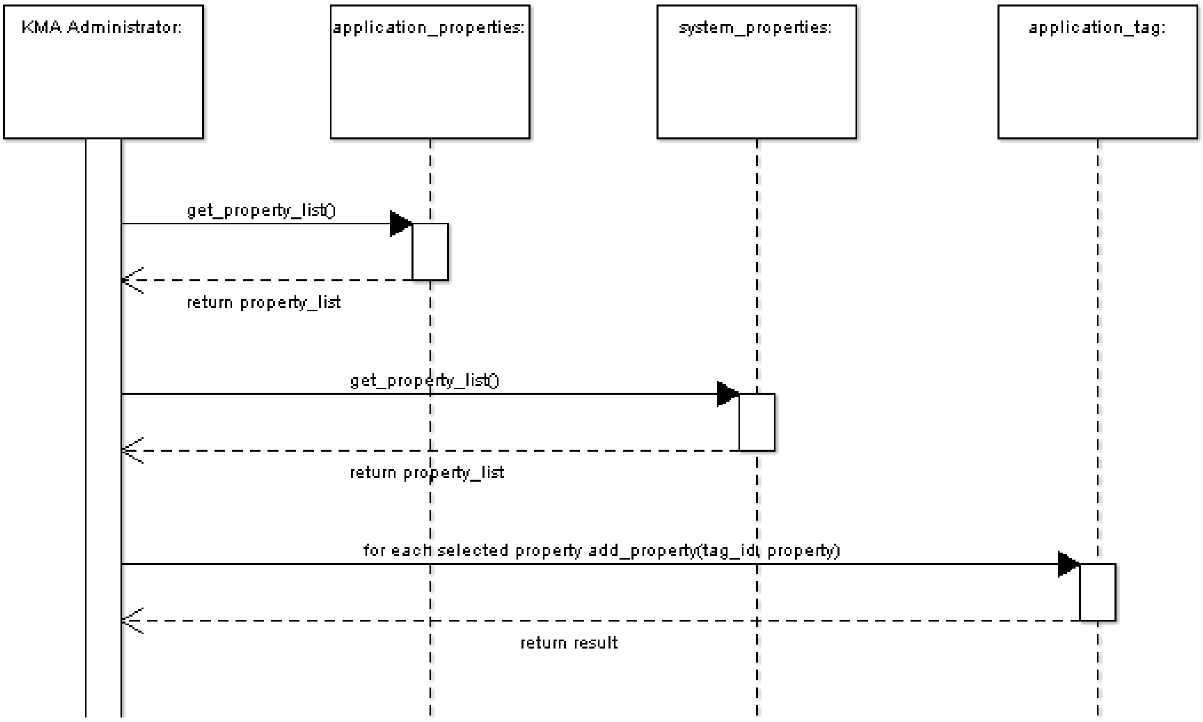

Figure 13: /UC 2210/ implementation

/UC 2220/

The KMA Administrator creates the list of files that will be protected through KMA data repositories for the secured application, using the function `add_new_file(path)`.

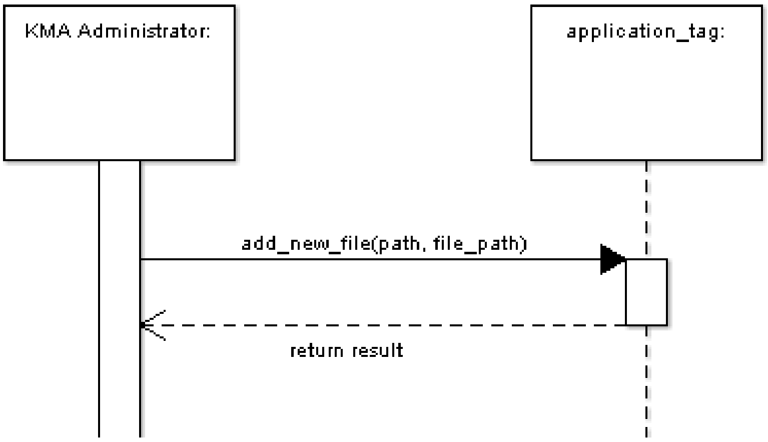

Figure 14: /UC 2220/ implementation

/UC 2230/

The KMA Administrator adds the secured application to the list of files to be certified, specifying that the type of `credential_id` it manages is the `tag`, which will be used by the `property_maker` to collect at runtime all properties, bound to the process, and the related values and tokens. In addition to the main executable of the application, also the binaries of all shared libraries the application depends are added to the list.

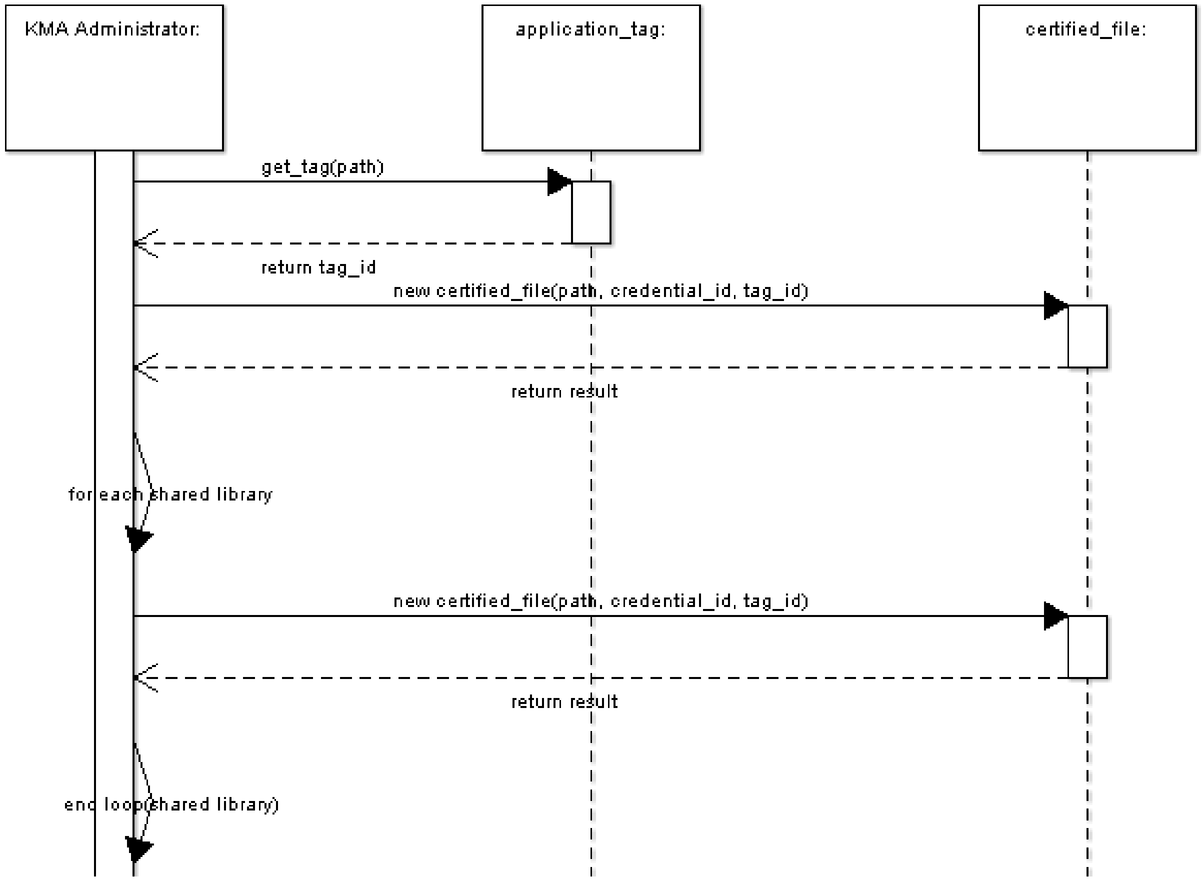

Figure 15: /UC 2230/ implementation

/UC 30/

After having restarted the TCG-enabled operating system, the KMA Administrator verifies the platform configuration after all components have been measured, by comparing the PCR values of the TPM device with the expected values. The function `verify_platform_configuration(pcr_values)` accomplishes this task. Then the KMA Administrator sends to KMA the `take_ownership` command by specifying the `admin_password` secret. The KMA generates a new key called `certkey`, using the function `gen_certkey()`, which is protected in two ways. One copy is sealed with the current configuration and used by the `property_maker` to extract tokens, which are sensitive data embedded in a `credential_blob` carried by application binaries (i.e. `certified_file`), used to authenticate the access to the KMA protected data repositories; another copy of `certkey` is bound and protected by the administrator's defined secret and it will be used to certify all binaries.

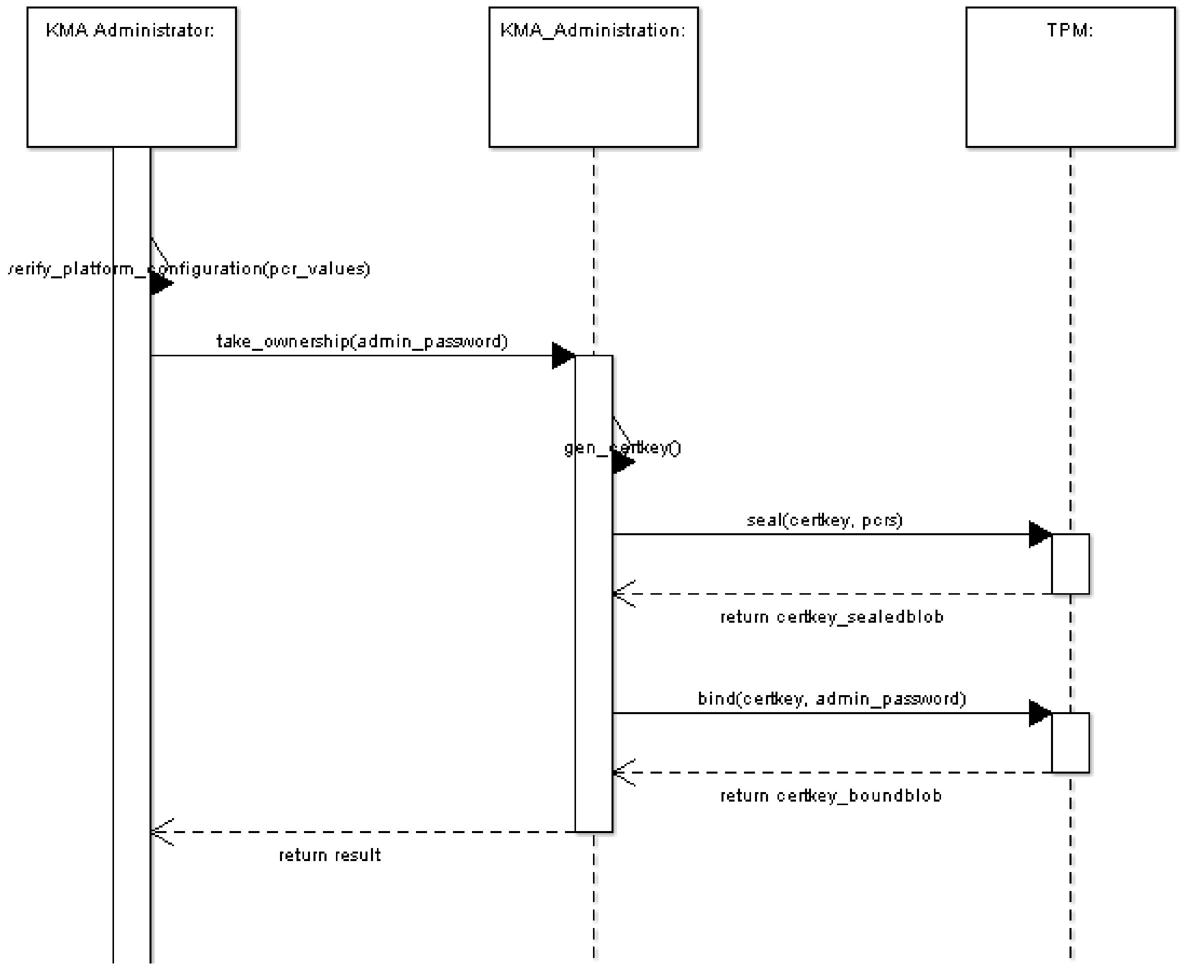

Figure 16: /UC 30/ implementation

/UC 40/

The KMA Administrator first retrieves the list of executables to be certified and verifies that each listed binary correspond to a trustworthy component (e.g. by checking it against a trusted site) by invoking the `get_binary_list()`function. Then, after the verification is done, KMA Administrator sends the command `certify()` to the `certify_service`, specifying the `admin_password`. In order to certify all binaries the `certkey` object bound to the TPM is retrieved from the `KMA_Administration` module by using the function `get_certkey_boundblob()`. Then the `certify_service` requests the decryption of the `certkey` by sending the `unbind` command to the `TPM`, with `certkey_boundblob` and `admin_password` as command parameters. If the operation is successful the `certify_service` generates a new token for each binary and creates a `credential_blob`, encrypted using `certkey`. For the binaries of the applications to be secured, the `certify_service` also retrieves the value for the `credential_id “tag”`, the property_list bound to it and the list of data files to be protected and include all these data into the `credential_blob`. Then creates an `application_MAC` which is a Message Authentication Code (MAC) i.e. a “symmetric signature” calculated using `certkey` over the binary file and the `credential_blob` and embedded in the modified application binary (in `certified_file`).

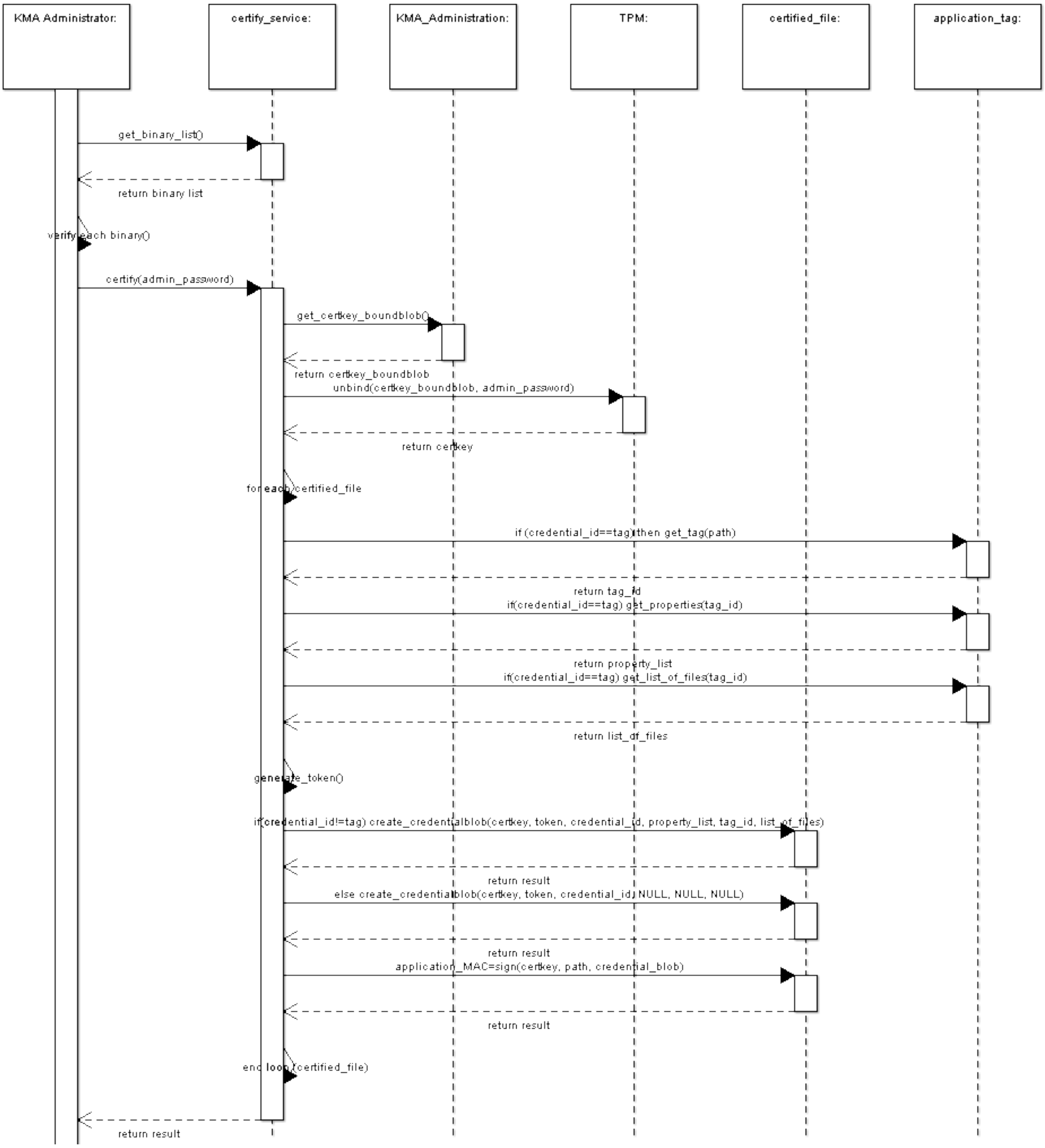

Figure 17: /UC 40/ implementation

/UC 50/

The KMA Administrator creates data repositories for secured applications: each repository is bound to a unique combination of values for the properties associated to each secured application's tag.

First the KMA Administrator calls the function `get_value_set(property)` in order to get the acceptable values for each property (this part of the implementation is described in Figure 18, while the following is described in Figure 19). Then he chooses the `cipher_method` (either TPM or direct), and starts the creation of a new data repository by calling the function `new_repository(properties: values: sources, cipher_method, admin_password)`. A collection of `property_elements` is created by the `Storage_container`. Each `property_element` is composed by the property name, the value, and where the current value can be retrieved: the source can be a an object from the `running_application` class or from the `system_properties_at_runtime` class, or a field, (e.g. the `tag` value of a secured application) in the `credential_blob` of the binary itself . This collection will be associated to the new data repository whose access is granted when the applications present at runtime the same combination of properties' values.

A `token` is associated to each `property_element`: the token will be combined with all other ones through the function `combine_tokens()` to create a unique `combined_token`: this will be used either directly as encryption key or as secret to perform the TPM `bind/unbind` functions. At runtime the `property_maker` will extract it from the `credential blob`. At this stage, since the application is not currently running, it must be extracted using the function `get_token(admin_password, credential_id)` from the `certified_file` class. For each credential other than the application (i.e. the tag) a single token is carried by the application that manages the credential, an additional function, `derive_token(token, property_value)`, must be performed in order to generate one different token for each possible property's value.

The `storage_container` starts the generation of a new `storagekey` for the data repository. If the `cipher_method` specified is “direct” the `combined_token` is used as encryption key for the `storagekey`, otherwise (`cipher_method` is “TPM”) the `storage_container` encrypts the `storagekey` performing a TPM `bind` using the `combined_token` as authorization secret.

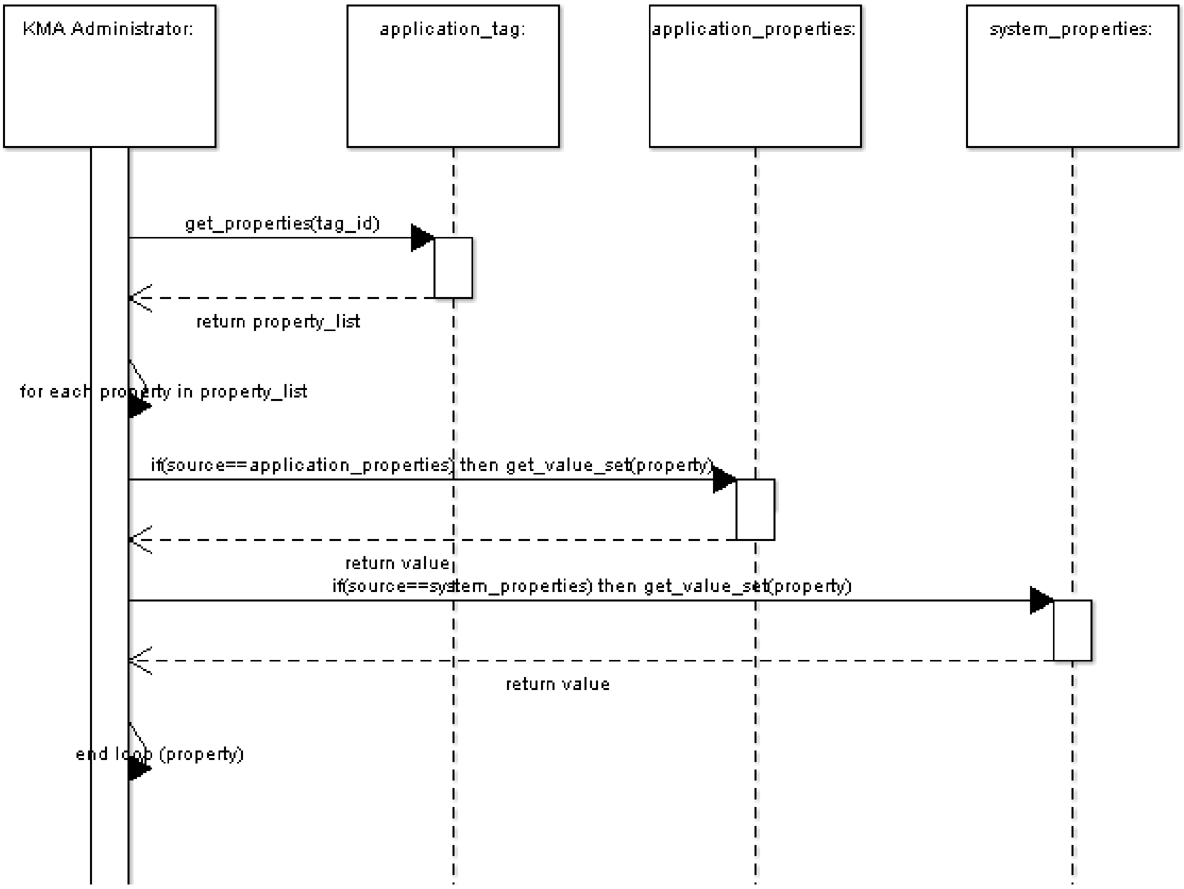

Figure 18: /UC 50/ implementation - part A

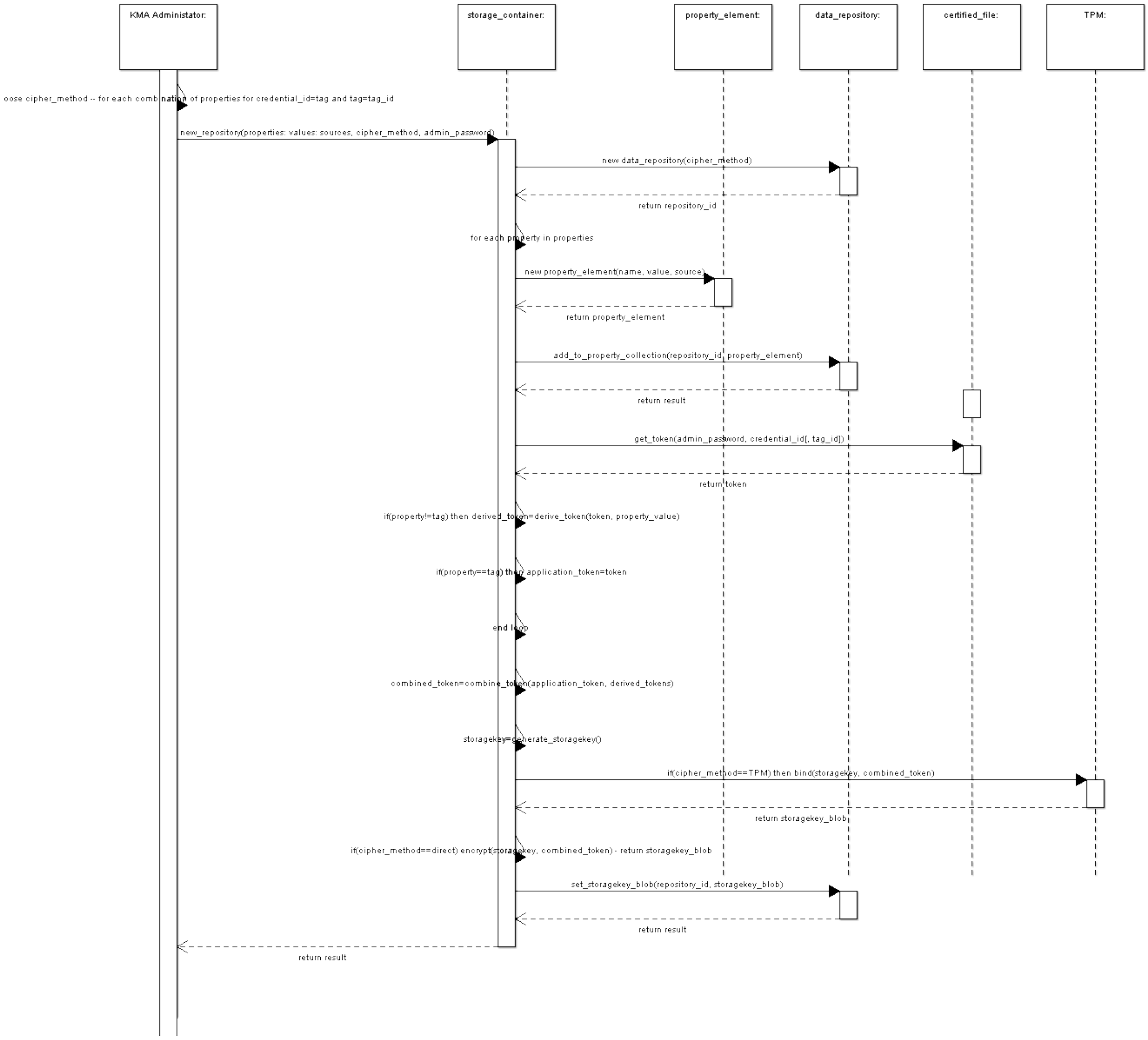

Figure 19: /UC 50/ implementation - part B

/UC 60/

As described in /UC 10/, KMA Administrator or User have executes the bootstrap of the `TCG-enabled operating system`. The latter executes the measurements of all components as defined by the KMA Administrator. Then it invokes the `activate()` function of the `KMA_Administration`. This consists of sending to the `TPM` the command `unseal` with the `certkey_sealedblob` as parameter. The operation is only successful if the current configuration matches the one defined by the KMA Administrator and used for KMA take ownership. The result, the `certkey`, is sent to the `property_maker` by calling the `set_certkey(certkey)` function to let it work propertly. It will be used to decrypt the `credential_blob` carried by the `certified_file` (i.e. secured applications and the applications managing credentials).

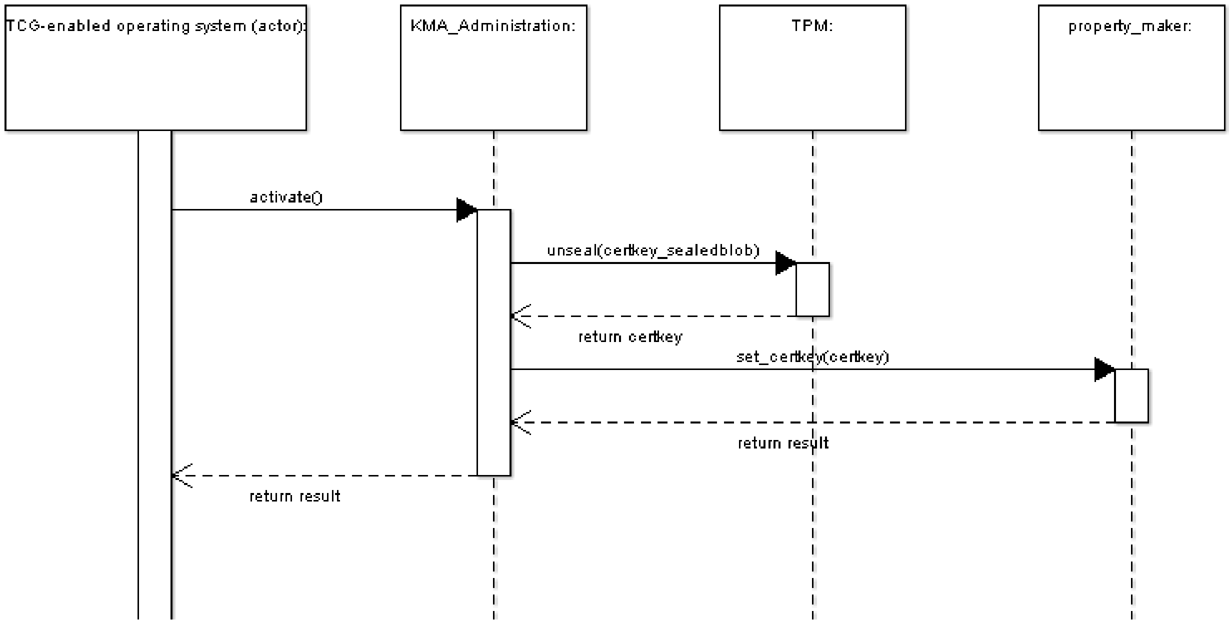

Figure 20: /UC 60/ implementation

/UC 70 – UC 80 – UC A0/

The actor executes an application that manages a credential. It can be the application that uses the protected repository (i.e. the secured application that provides the “application_credential”) or other applications that only manage the credentials. The `TCG-enabled_operating_system` notifies to the `property_maker` a new process instance of the application with the `process_identifier` and passes to it the `credential_blob` and the `application_MAC`, carried by the binary executable. Then the `property_maker` first verifies the integrity of the binary and the carried credential_blob by calling the function `verify_binary_integrity(binary_file, credential_blob, application_MAC, certkey)`; then, if the verification is successful, the `property_maker` decrypts the `credential_blob` (using `certkey`) thus obtaining the `decrypted_credential_blob`; from it the `credential_id`, the `token` are extracted and, for the application (i.e. “tag”) credential, also the `tag_id` value, the bound `property_list` and the `list_of_files`, i.e. the application data to be protected.

If the `credential_id` extracted from the `decrypted_credential_blob` is not the `tag`, the `property_maker` retrieves, by calling the function `get_property_source (property)` the identifier of the `TCG-enabled_operating_system` component that will report the “current” value when an application will try to access (see /UC B00/) the data repository: it can be from the `system_properties_at_runtime` or from the `running_applications`.

The last action is the creation by the `property_maker` of a new object `runtime_property` or `runtime_tag_property`, both storing the token extracted from the `decrypted_credential_blob`. In the first case, since only single token is embedded in the application managing credentials, the token associated to the specific value assumed by the property bound the credential must derived, using the `derive_token(token, property_name, property_value)`function. In the second case, the object `runtime_tag_property` stores an additional information, the process identifier, that binds the running process of a secured application to the value of the property (tag) associated to the application credential (i.e. the application itself).

In the case of a system property, /UC 70/ is executed not only when the application managing the related credential is loaded but also at any subsequent change of the property value: the application managing the credential will report the change and will trigger KMA to replace the token bound to the old value via `notify_system_property(property, value, credential_blob)`.

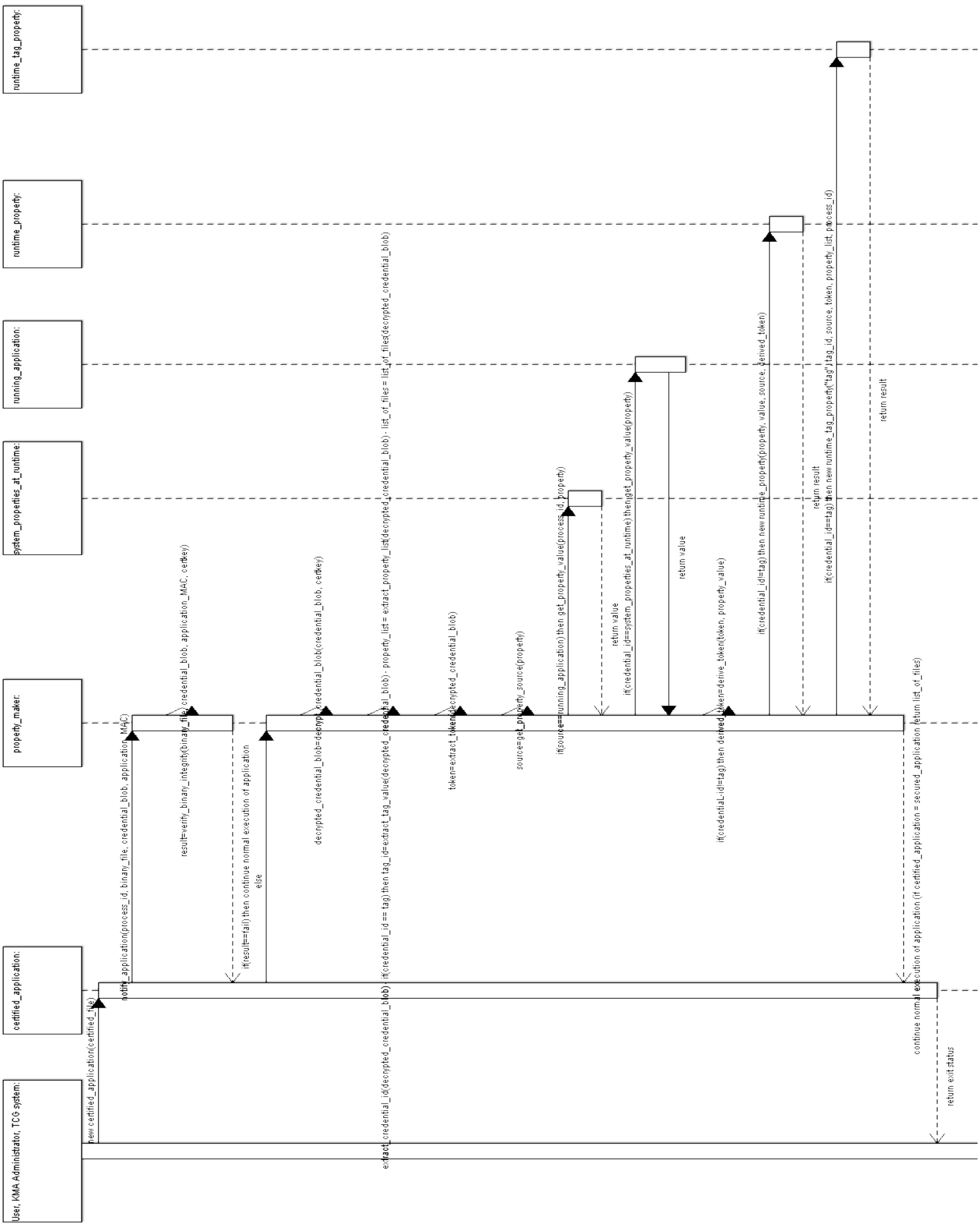

Figure 21: /UC 70 - 80 - A0/ implementation

/UC B0/

The `secured_application`, is started by the User in UC 90 and provided the "application credential" in /UC A0/.

First the `secured_application`, by using the function `request_repository(process_id)`, obtains from the `storage_container` a handle that is used to perform a operation on its protected data repository. This operation is described in /UC B00/.

Then, for each path of the files present the list defined by the KMA Administrator in UC 2220, the `secured_application` requests to the `storage_container` the execution of the `protect_application_data(handle, path)` function.

The `storage_container`, using the handle value, retrieves from a `repository_handle` object, the `repository_id` associated to the `process_id` of the secured application and the `crypt_handle` that will be used to encrypt/decrypt data using the `crypto_service_provider`. Then the `storage_container` encrypts the file using the `crypto_service_provider` and creates for the `repository_id` a new `encrypted_data` object with the same path name and the data encrypted.

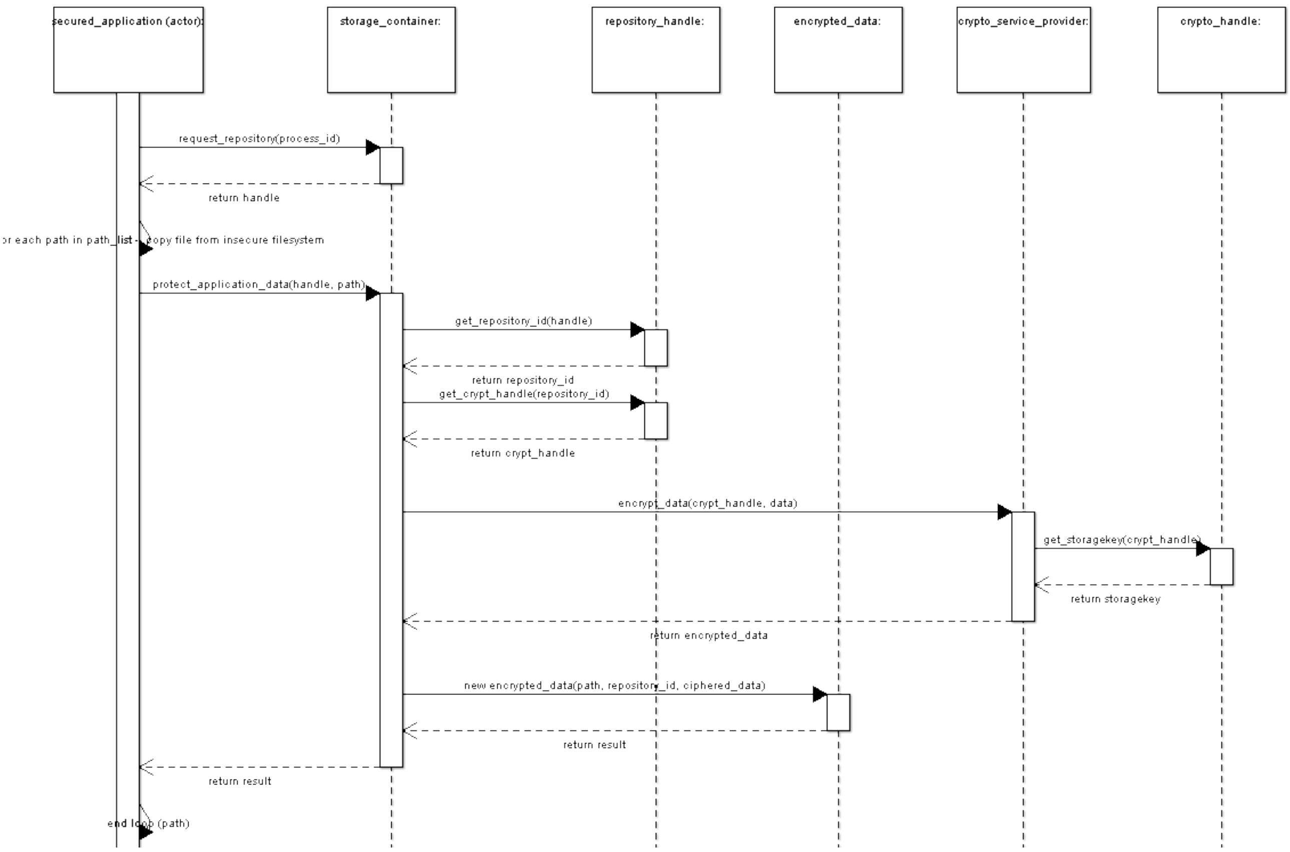

Figure 22: /UC B0/ implementation

/UC C0/

The secured_application, is started by the User in UC 90 and provided the “application credential” in /UC A0/.

First the secured_application, by using the function request_repository(process_id), obtains from the storage_container a handle that it will use to perform a operation on its protected data repository. This operation is described in /UC B00/.

Then, for each path of the files present the list defined by the KMA Administrator in UC 2220, the secured_application requests to the storage_container the execution of the get_protected_data(handle, path) function.

The storage_container, using the handle value, retrieves from a repository_handle object, the repository_id associated to the process_id of the secured application and the crypt_handle that will be used to encrypt/decrypt data using the crypto_service_provider.

Then, in the first case it retrieves the encrypted_data object with the given path, decrypts the content using the crypto_service_provider and returns it to the secured_application. In the second case it retrieves the existent encrypted_data, encrypts the data given by the secured_application and saves them in the object.

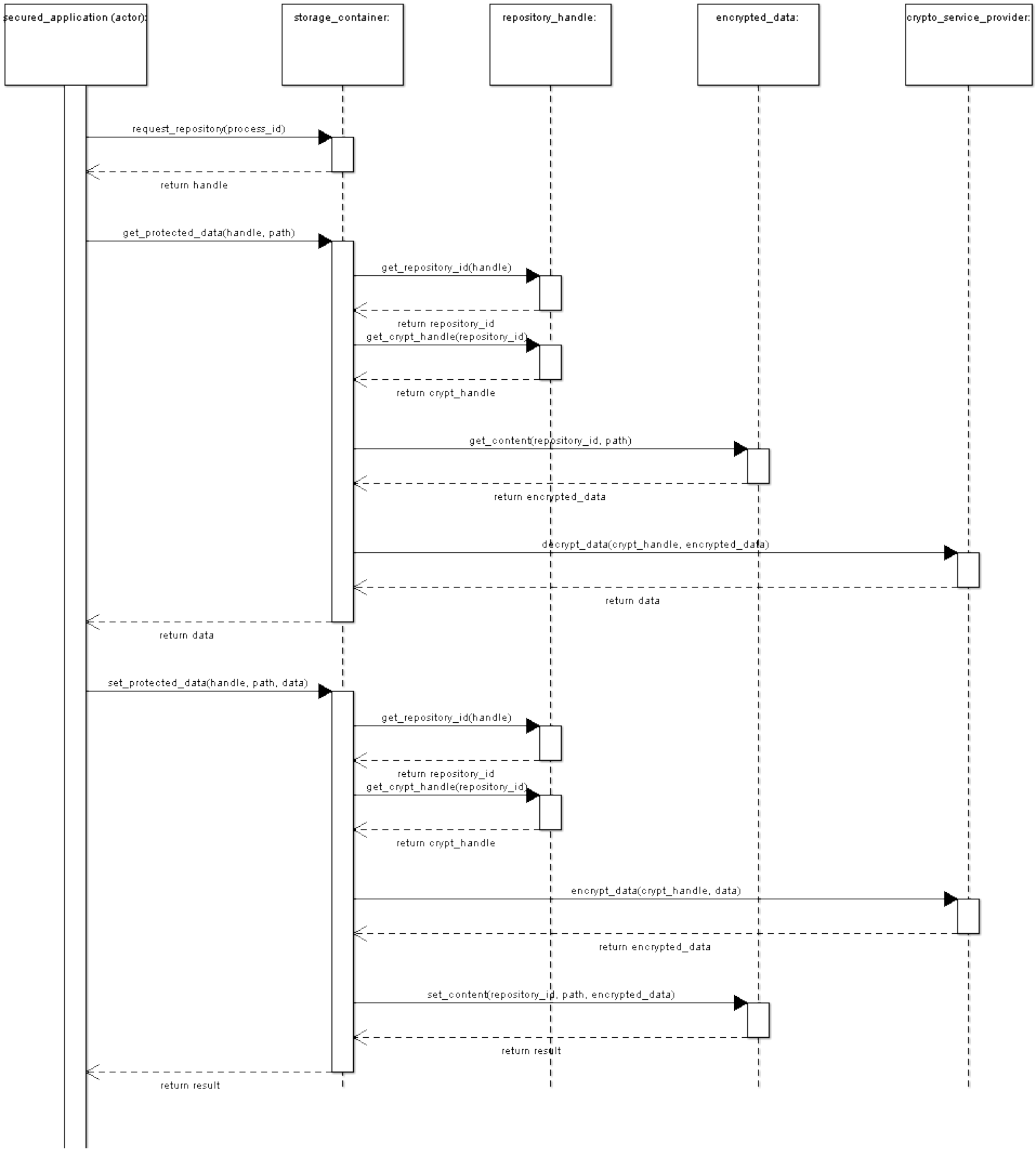

Figure 23: /UC C0/ implementation

/UC D0/

The `secured_application`, is started by the User in UC 90 and provided the “application credential” in /UC A0/.

First the `secured_application`, by using the function `request_repository(process_id)`, obtains from the `storage_container` a handle that it will use to perform a operation on its protected data repository. This operation is described in /UC B00/.

Then, for each path of the files present the list defined by the KMA Administrator in UC 2220, the `secured_application` requests to the `storage_container` the execution of the `restore_application_data(handle, path)` function for all files in the list defined by the KMA Administrator in UC 2220.

The `storage_container`, using the handle value, retrieves from a `repository_handle` object, the `repository_id` associated to the `process_id` of the secured application and the `crypt_handle` that will be used to encrypt/decrypt data using the `crypto_service_provider`.

The behaviour is the same as in /UC C0/, when performing the `get_protected_data` function, but the `encrypted_data` objects are deleted and are no longer available for the bound `data_repository`. Then the `secured_application` copies the data returned from the `storage_container` to the insecure filesystem.

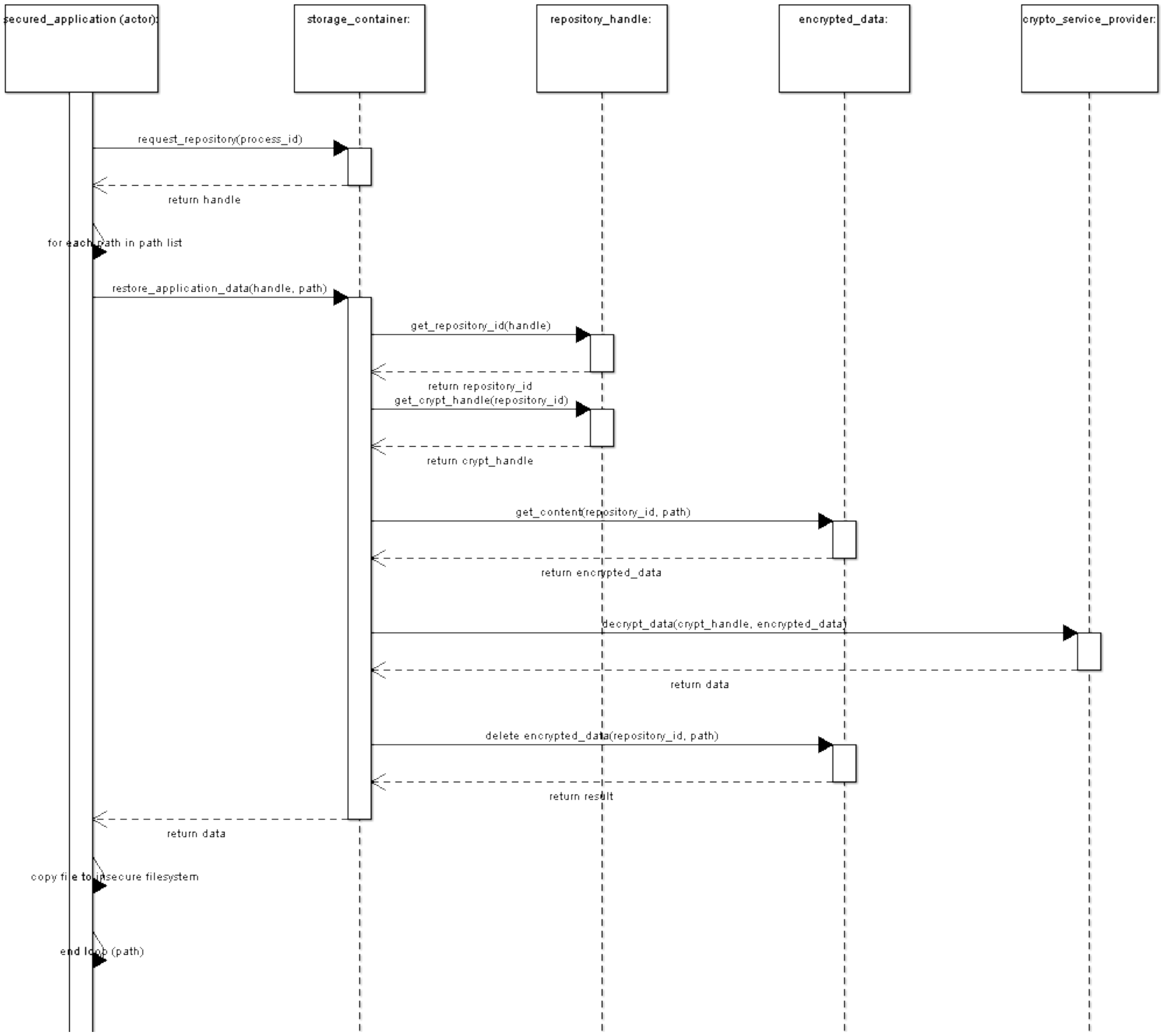

Figure 24: /UC D0/ implementation

/UC B00/

The `secured_application` requests to the `storage_container` the access to its data repository, giving its `process_identifier`. The complete sequence of interactions is reported in Figure 26.

The interaction between `storage_container` and `property_maker` to execute the function `get_properties(process_identifier)` is expanded in Figure 25 and described in the following. The `storage_container` requests to the `property_maker` the collection of the `runtime_property` and `runtime_tag_property` objects bound to a given process identifier and of the `runtime_property` objects bound to the system (i.e. holding a system property). The `property_maker` retrieves from a `runtime_tag_property` object the `tag` value and the `property_list` associated to the running process of the `secured_application`. Then for each property first it checks if the property is related to the `secured_application`. In this case the current value of the property is reported from the `running_application` by calling the function `get_property_value(process_identifier, property)`.

The `property_maker` collects all `property_element` objects which match the criteria `property` and `value` and returns the pairs (`property`, `value`) to the `storage_container`.

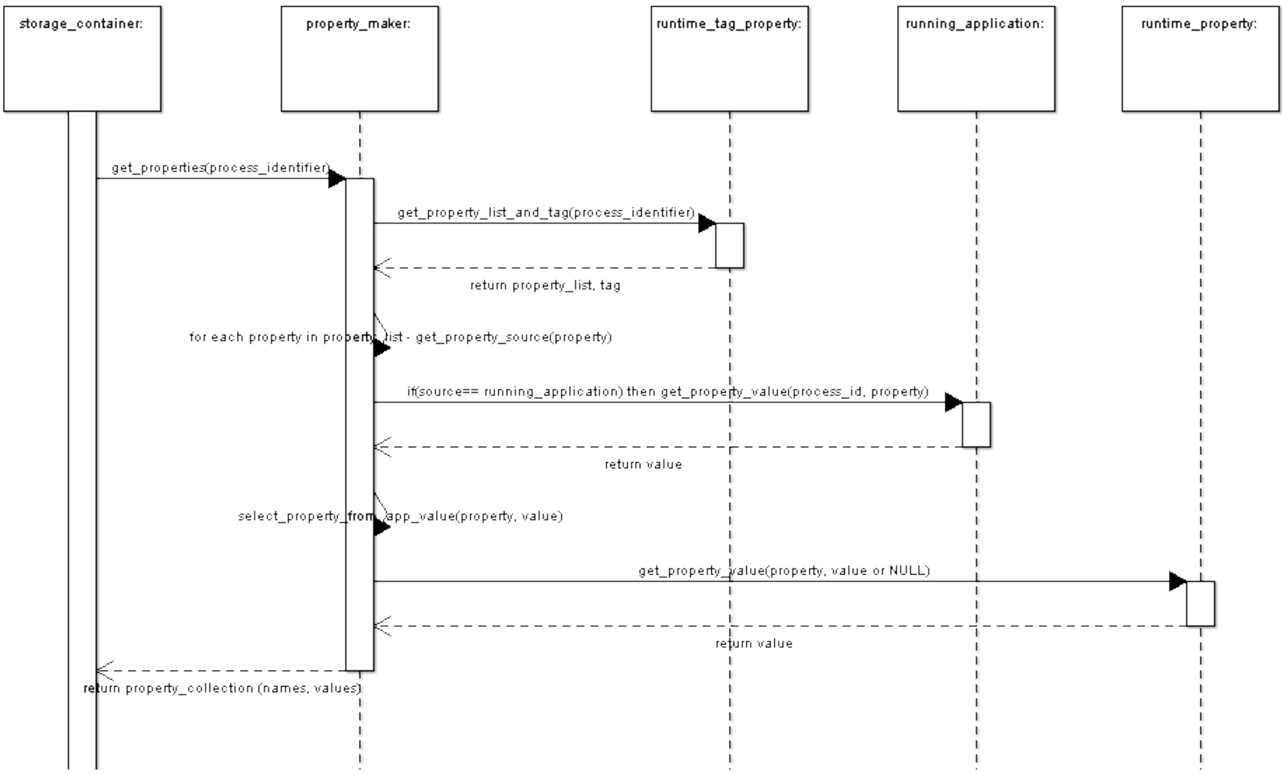

Figure 25: /UC B00/ implementation - part A

The complete sequence for accessing a protected repository is reported in Figure 26 and described in the following. The `secured_application` requests to the storage_container the access to its data_repository, configured by the KMA Administrator, giving its process_identifier. The storage_container first retrieves the property_element collection (as described in Figure 25), by calling the function get_properties(process_identifier), then it searches for a data repository, using the find_repository(property_collection) function. If one repository is found, it retrieves the storagekey_blob using the function get_storagekey_blob(repository_id) and the cipher_method using get_cipher_method(repository_id).

Then the storage_container creates a new context from the crypto_service_provider using the function new_context(process_id, cipher_method, storagekey_blob). The crypto_service_provider retrieves the property_collection from the property_maker by using the function get_properties(process_identifier); the selection of only the property elements carrying the values actually assumed by the process running the secured_application is performed (it is not described in Figure 26, see Figure 25 for details). Then the property_maker extracts the tokens from each element of the property_collection. Then it computes the combined_token by calling combine(tokens). Lastly if the cipher_method of the data repository is "direct" the crypto_service_provider decrypts the storagekey_blob using the combined_token as decryption key, otherwise (i.e. cipher_method is "TPM") requests to the TPM a unbind operation using the combined_token as secret for the authorization. If all operations are completed successful the crypto_service_provider creates a new crypto_handle object which takes as arguments the process_id, the cipher_method and the storagekey and returns to the storage_container the crypt_handle reference of the created crypto_handle object. The storage_container creates a new repository_handle object which bind together a generated repository handle, the repository_id and the crypt_handle that will be used to encrypt/decrypt data. The storage_container returns the handle to the secured_application. Such handle will be used in all /UC B0/, /UC C0/ and /UC D0/ by the secured_application to manipulate its protected data.

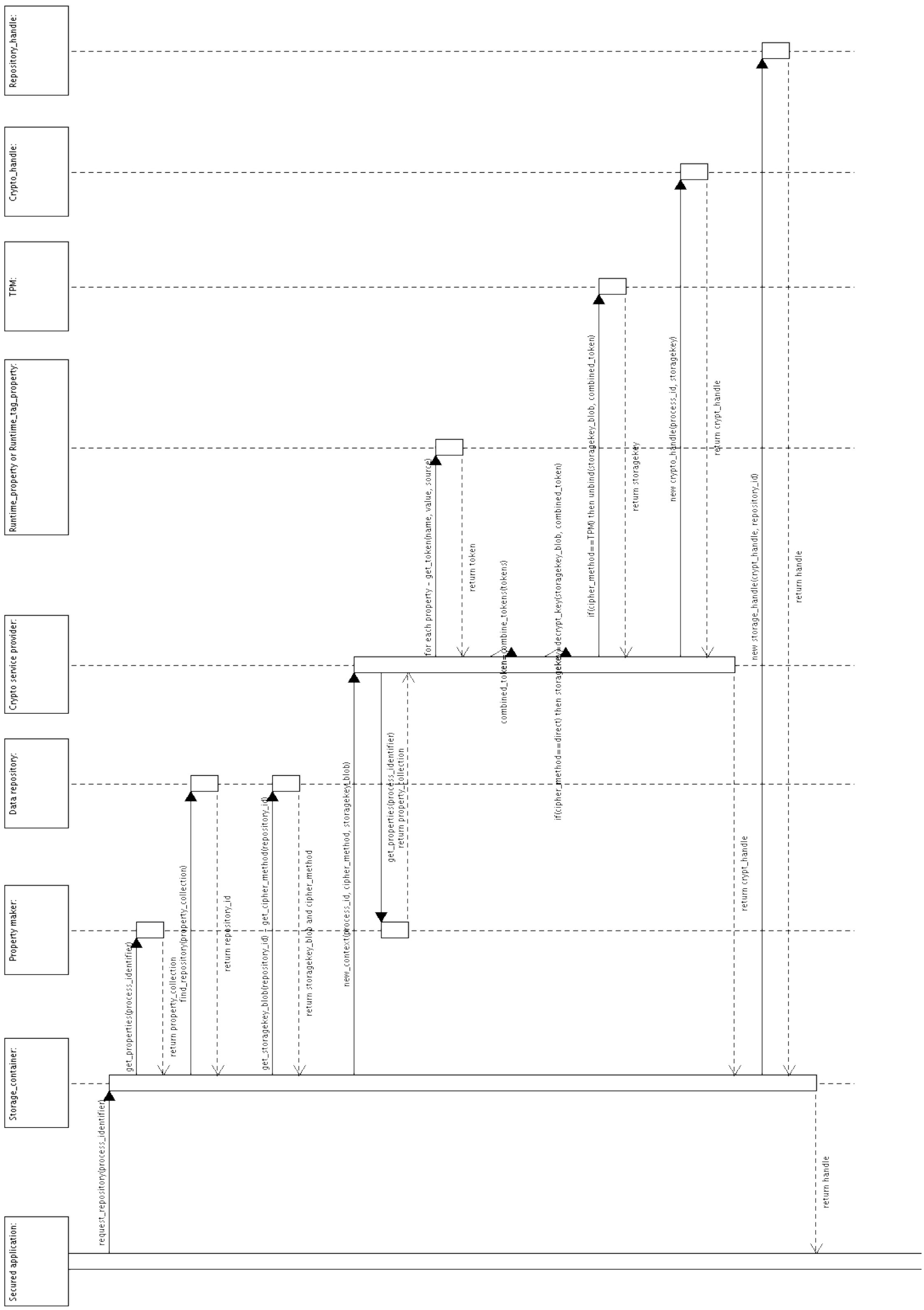

Figure 26: /UC B00/ implementation - part B

7 List of Abbreviations

Listing of term definitions and abbreviations used in this document (IT expressions and terms from the application domain).

Abbreviation	Explanation
KMA	Key and data Management Adaptation layer
OS	Operating System
PKCS	Public Key Cryptography Standard
SRK	Storage Root Keys
SSH	Secure SHell
TCG	Trusted Computing Group
TPM	Trusted Platform Module
TSS	TCG Software Stack

8 Related Work

/1/ TCG TPM Main Specification (parts 1,2,3)
July 9, 2007,
Version 1.2 Level 2 Revision 103

/2/ IETF RFC 4251, The Secure Shell (SSH) Protocol Architecture
January, 2006

/3/ IETF RFC 2401, Security Architecture for the Internet Protocol (IPsec),
November, 1998

/4/ RSAlab PKCS #11: Cryptographic Token Interface Standard
January, 2007
v2.20 and v2.20 Amendment 3, Revision 1

/5/ TCG Software Stack (TSS) Specification
March 7, 2007,
Version 1.2, Level 1, Errata A

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D03c.3 SSL/TLS DAA-enhancement specification

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Dissemination level	Public
Revision	FINAL | 1.10

Instrument	IP	**Start date of the project**	1st November 2005
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1 Introduction

Secure channels allow two or more entities to communicate securely over insecure networks. These channels use cryptographic primitives to provide confidentiality, integrity and authentication of network messages. Trusted Computing (TC) technology allows to extend the network protection to the peers involved in the communication. TC, in facts, allows a platform with TC-enabled hardware to provide cryptographic proofs about its behavior. Using these information, the counterpart can be guaranteed about the security of the message not only while it is transmitted, but also after it is received on the TC-platform.

2 The Direct Anonymous Attestation (DAA) protocol

Direct Anonymous Attestation (DAA) ([6]) is a privacy-friendly protocol that was designed to overcome the privacy issues of the privacy CA. In particular, the main problem related with the use of a privacy CA, is that it is possible for the privacy CA to disclose sensitive data that could allow a third party to link different remote attestation made by the same platform and, therefore, breaking the platform's privacy. DAA overcomes this problem using a zero-knowledge proof.

In this section is given an overview of the DAA protocol and describe how this protocol can be used to provide anonymous authentication.

The DAA scheme involves four principals, three mandatory and one optional:

- TC-platform equipped with a TPM
- DAA issuer
- Verifier
- A revocation authority. This last entity is optional

The purpose of the DAA is to convince the verifier that a signature received from the TC-platform was made using a genuine TPM, without revealing the actual identity of the platform (in TCG architecture the identity of a platform is represented by the endorsement key (EK) of the TPM).

The DAA is composed of two protocols: the Join protocol and the Sign protocol.

The Join protocol happens between the platform and the issuer and results in the TC-platform receiving a DAA credential, so it can authenticate to Verifiers. In details, the issuer checks that the platform is equipped with a genuine TPM and, if this is the case, issues to the TPM the DAA credentials. This protocol occurs once for a TC-platform and has to happen before it can meaningfully interact with Verifiers.

The Sign protocol allows a verifier to decide if a signature received from a TC-platform was made using a genuine TPM or no. Unlike with other protocols (e.g. those involving the use of an AIK), the Verifier does not need to see the DAA credential, but the proof of the existence of the credentials is provided through a zero-knowledge proof.

In detail, the DAA signature is a group signature that provides to the verifier an evidence that the platform belongs to the group of platforms that received the DAA credentials from a particular issuer.

DAA provides both complete anonymity and pseudonymity. The complete anonymity means that the verifier can only verify if the platform that made the DAA signature belongs to the group of platforms that received the DAA credentials from the issuer. Therefore each issuer represents a group of platforms, but each platform can belong to different groups through DAA credentials obtained from different .

The pseudonymous option allows a verifier to link together different signatures made by the same platform. Notably, the verifier can recognize the pseudonym under which a particular platform made a signature and link it to previous signatures made by the same pseudonym, but it is not possible for the verifier, to link the pseudonym with the actual platform.

Furthermore, the DAA signature can selectively provide a zero-knowledge proof on a subset of the attributes that belongs to the DAA certificate; for instance, it is possible to prove that the expiration date of a DAA Credential has not been reached, without revealing it.

Finally, the DAA protocol allows to use a trusted third party as a revocation authority (RA). The RA can revoke the anonymity or the pseudonymity provided by the DAA credentials under particular circumstances determined by a policy. When the RA is used, the platform encrypts its identity using the public key of the RA; the verifier then can forward the encrypted identity of the platform to the revocation authority that reveals the identity of the platform if the circumstances determined by the policy apply.

Note that in this version of the document, neither the attributes or the revocation authority are used.

3 Using the DAA for authentication

It is possible to use the DAA to authenticate a platform, and therefore to authenticate its owner, while guaranteeing its privacy. In general, a TC-enabled platform receives the DAA credentials from an issuer, and many different verifiers challenge the platform to verify if it belongs to the group of platforms that received the DAA credentials from that issuer; the TPM guarantees that the DAA credentials cannot be shared with other platforms and actually belong to the platform, while the DAA protocol guarantees that it is not possible to link one challenge to the actual identity of the platform, preserving the privacy of the platform.

The DAA signature allows a verifier to authenticate the platform that made the signature w.r.t. a group of platforms (i.e. those that received the credentials from a particular issuer), and the platform is assured that it is not possible to link such authentication to its real identity.

3.1 Application scenario

A possible scenario for a DAA-based authentication for a service is the following: a company wants to allow access to the internal network only to authorized platforms. This requirement can be fulfilled using a TPM-enabled platform and the DAA protocol:

1. The company issues a DAA certificate to each laptop before giving it to the employee.
2. The company verifies that only allowed platforms (i.e. those that received a DAA certificate) access the network with a DAA challenge.

In this scenario, the company is assured that only certified laptops can access the network, and the employees are guaranteed that the company can not link the authentication to their specific platform. The company might also desire to link the accesses to different services provided to the remote users. In this case the pseudonymous option provided by DAA can meet the requirement.

3.2 Combining TLS and DAA protocols

An implementation of a protocol for anonymous authentication through the DAA signature is possible by enhancing the TLS protocol (see [3]) to implement the concepts described in section 5. Using the TLS protocol has many advantages: it is widely supported, many open source implementations are available and it is possible to extend the protocol without losing backward compatibility.

The latter point in particular is helpful because allows to design a protocol that can be used when a TPM is available to provide anonymous authentication, but can also work on platforms without TC-enabled hardware providing classical authentication. Moreover, TLS also provides confidentiality and integrity of the messages exchanged on the channel.

4 Enhancing TLS protocol (informative)

4.1 TLS protocol

The Transport Layer Security (TLS) protocol implements a secure channel, a client/server communication guaranteeing authenticity, integrity and confidentiality of the exchanged data. Two main and subsequent phases can be identified: during the first one, a *handshake* protocol is run by peers to authenticate themselves to each other and agree on a session key; then, once the handshake is completed, the communication begins and the peers exchange messages over the established secure channel.

In Figure 1 a diagram shows the messages exchanged by client and server during the TLS handshake.

It is possible to extend the TLS handshake by defining:

1. extensions to the hello messages according to the framework specified in [4]
2. new data units carried over an additional handshake message, called supplemental data and specified in [5], which can be exchanged between client and the server in both directions

All definitions recalled in the following are expressed using the Presentation Language specified and used in [3].

4.2 Hello extensions

The hello extensions consist of additional data that may be used to add functionalities to TLS and are designed to be backwards compatible. Indeed the extensions must be negotiated: therefore TLS clients supporting the extensions can communicate with TLS servers not supporting them and vice versa.

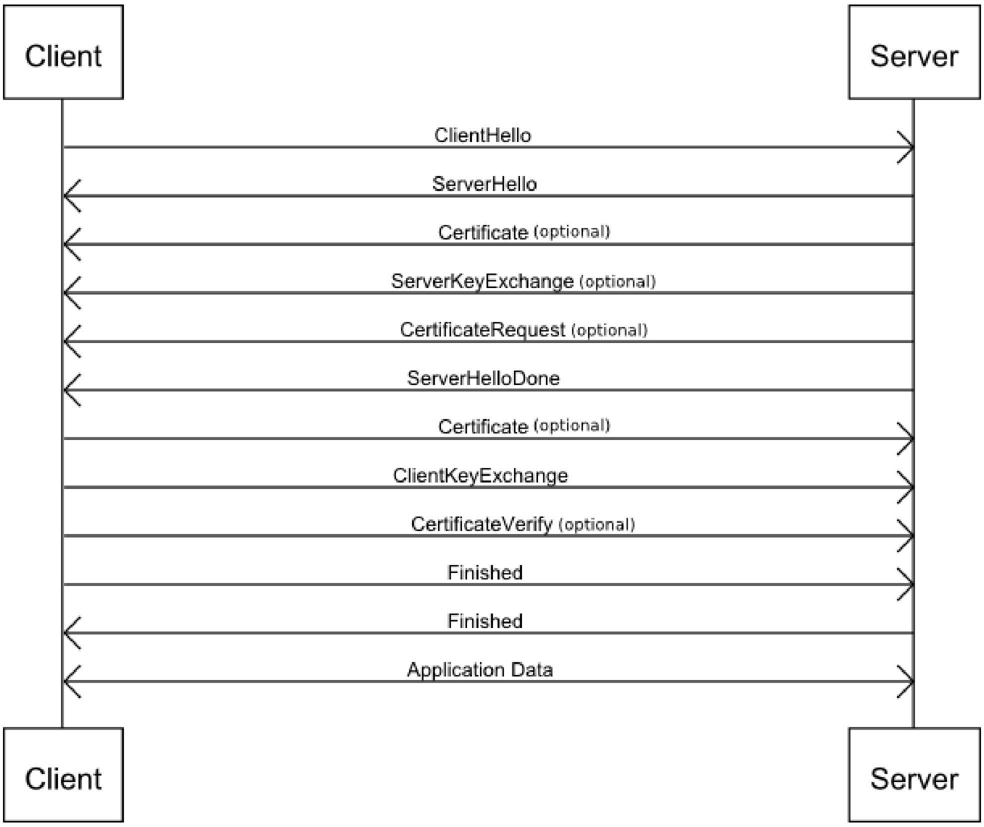

Figure 1: Messages exchanged during the TLS handshake protocol

The extended client hello message format is:

```
struct {
      ProtocolVersion client_version;
      Random random;
      SessionID session_id;
      CipherSuite cipher_suites<2..2^16-1>;
      CompressionMethod compression_methods<1..2^8-1>;
      Extension client_hello_extension_list<0..2^16-1>;
} ClientHello;
```

and, symmetrically, the extended server hello message format is:

```
struct {
      ProtocolVersion server_version;
      Random random;
      SessionID session_id;
      CipherSuite cipher_suite;
      CompressionMethod compression_method;
      Extension server_hello_extension_list<0..2^16-1>;
} ServerHello;
```

where **client_hello_extensions_list** and **server_hello_extension_list** represent the new field containing a list of extensions, while the other fields have the same meaning as in the base TLS specification ([3]).

Each extension is defined as:

```
struct {
      ExtensionType extension_type;
      opaque extension_data<0..2^16-1>;
} Extension;
```

where **extension_type** is (the unique identifier of) the type of the extension and **extension_data** contains data specific for the particular extension type.

Clients and servers using the extensions must adhere to the following rules:

1. if the client wants to request the server extended functionalities, its sends the extended client hello message instead of the standard hello message
2. if the server supports the extended functionalities required by the client, it may reply with an extended server hello that contains a subset of the extensions sent by the client in order to signal to the latter which functionalities will be provided

The extended server hello message can only be sent in response to received extended client hello message and cannot contain any extension that was not previously requested by the client. The complete definition of the TLS extension framework is specified in [4].

Each **Extension** must be defined by explicit specification. Five new extensions are specified in [4].

Figure 2: Supplemental data exchange in TLS handshake protocol

4.3 Supplemental data message

The supplemental data is an additional message of the TLS handshake, specified in [5], to carry extra authentication and/or authorization data units for the application establishing the secure channel.

Different data units, called supplemental data entries, can be transferred from server to client and vice versa: however, for each direction all supplemental data entries must be carried over a single message exchanged during the handshake, as shown in Figure 2.

The supplemental data message is defined as:

```
struct {
      SupplementalDataEntry supp_data<1..2^24-1>;
} SupplementalData;
```

where **supp_data** is a list of items defined as:

```
struct {
      SupplementalDataType supp_data_type;
      uint16 supp_data_length;
```

```
        select(SupplementalDataType) { }
  } SupplementalDataEntry;

  enum {
        (65535)
  } SupplementalDataType;
```

Each **SupplementalDataEntry** is defined by a unique type (**supp_data_type**) and includes the length (**supp_data_length**) and the value (**select (SupplementalDataType) { }**).

If present, the **SupplementalData** message must contain at least one non empty **SupplementalDataEntry** which is then used by the application.

Each **SupplementalDataEntry** must be negotiated between client and server via specific hello extension; receiving an unexpected **SupplementalDataEntry** must result in a fatal error, and the receiver must close the connection.

Furthermore, supplemental data entries must not be evaluated during (and interfere with) the TLS handshake by the protocol implementation but only at the end of the handshake and by the applications.

Each **SupplementalDataEntry** must be defined by explicit specification. Supplemental data entries can be sent by client and/or server according to their definition. The supplemental data message must be sent by either party (client/server) to the other one according to which data entries have to be carried in each direction.

5 DAA-enhanced TLS (DAA-TLS)

5.1 Overview

TLS supports different key exchange and authentication methods. **DH_anon** key exchange implies non-authenticated (i.e. anonymous) TLS sessions. Any other key exchange algorithm, instead, implies server authentication being mandatory and client authentication being optional.

Enhancing TLS with DAA leads to additional authentication methods. In this document the use of DAA is specified only for the client authentication and with **RSA** key exchange method. Subsequent specifications may define further methods considering DAA also for the server authentication and other key exchange methods supported by TLS.

In this specification DAA is used to add a group authentication scheme for client, with two variants: complete anonymity within the group or use of a pseudonym chosen by the verifier to let it link different client authentications made by the same platform with specific group credentials (i.e. with DAA credentials released by a specific issuer).

For brevity, in the following the former variant will be referred to as DAA authentication while the latter as DAA authentication with pseudonymous (or also DAA pseudonymous authentication).

Table 1 summarizes all possible authentication methods for a TLS implementation adherent to this specification (i.e. supporting DAA-TLS).

Complete anonymous TLS session	Standard TLS with **DH_anon** key exchange method
Server authentication only	Standard TLS with all key exchange methods but **DH_anon**
Client and server authentication	Standard TLS with all key exchange methods but **DH_anon**
Group authentication for client and standard RSA authentication for server	DAA-enhanced TLS with **RSA** key exchange method
Group authentication with pseudonym for client and standard RSA authentication for server	DAA-enhanced TLS with **RSA** key exchange method, pseudonym specified by verifier

Table 1: Authentication methods for DAA-TLS capable client and server

In this document the enhancement of TLS with DAA is specified through the definition of a new hello extension and a new supplemental data entry, both expressed using the Presentation Language specified and used in [3].

5.2 Summary of DAA-TLS capabilities and protocol flow

DAA is composed of two different sub-protocols: Join where the platform obtains a DAA credential from an issuer and Sign where the platform performs a DAA signature and a verifier verifies it.

In this specification only the DAA Sign sub-protocol is used to enhance TLS for client authentication. The DAA Join sub-protocol is out of scope and not described: it is assumed as previously run to obtain the DAA credential required by DAA Sign.

The enhancement defined throughout this section (Section 5) is generic to support any specification of DAA; in the next sections, instead, a binding to a particular DAA specification and design (i.e. TCG TSS/TPM) is defined.

In this document, the revocation of DAA credentials and revocation checking, whilst essential elements for authentication, are not considered as part of DAA-TLS and, therefore, not specified, but left to the application.

The DAA Sign sub-protocol involves a platform and a verifier; there roles are respectively mapped onto client and server TLS roles. In order to preserve its privacy, the client authenticates itself by performing a DAA signature verified by the server.

The protocol flow is:

1. The client starts the TLS handshake by sending the **ClientHello** message. The latter must contain an extension to inform the server that the client is capable of using DAA for authentication.
2. If the server agrees on using DAA for client authentication, it replies to the client with the **ServerHello** message by sending back the same extension. In the hello extension, the server also specifies the nonce needed for the DAA signature; moreover, if the server wants the client to use DAA authentication with pseudonymous, it must also specify the basename that the client must use while performing the DAA signature. If the client does not accept to use the

pseudonym, it must terminate the handshake. Otherwise the latter continues and the DAA authentication for client and the related variant is then agreed on.

3. The server must also request the client authentication sending the **`CertificateRequest`** message. This is needed to bind the TLS session to the DAA signature. See section for further details.
4. The client performs the DAA signature over a self-signed client certificate and sends it to the server using a **`SupplementalDataEntry`** carried over the **`SupplementalData`** message. The former also contains all data necessary to verify the DAA signature.
5. The TLS handshake protocol continues according to [3] until its completion.
6. To comply with [5], any action caused by the evaluation of the data carried by **`SupplementalData`** must be performed after the handshake is completed. Therefore, before accepting any data from the channel, the server must conclude the verification of the DAA signature over the client certificate. This operation can not happen during the handshake, but must take place immediately after the handshake is completed. If the verification fails, the server must shut down the TLS channel; otherwise the client is successfully authenticated and the data exchange over the secure channel can start.

The TLS protocol extended to support the DAA authentication of the client is shown in Figure 3.

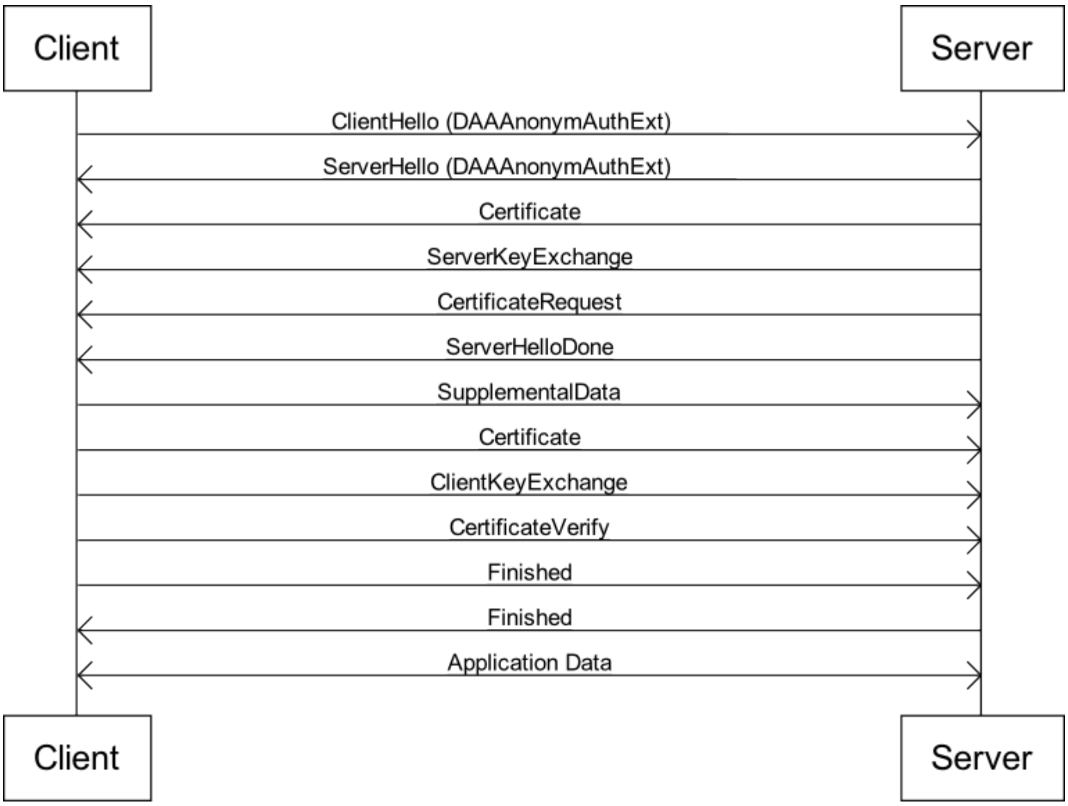

Figure 3: TLS extended to support DAA authentication (DAA-TLS)

5.3 Binding between TLS channel and DAA authentication

In order to complete the client authentication, it is required to provide the binding between TLS session and DAA authentication. This is must be done by the client by DAA-signing a client certificate. For the purposes of this specification, the client certificate must be a self-signed X.509v3 certificate, DER-encoded, including all extensions required by TLS specification [3]. In subsequent specifications, a format for DAA signature algorithm for X.509 certificates may be defined in order to replace the self-signed client certificate with another DAA-signed. This would imply, however, a revision of the DAA-TLS protocol as defined in this document.

The binding must be provided as follows:

1. The client must create a self-signed certificate with no indication about its identity (e.g. a random distinguished name) for each TLS handshake.
2. The TLS handshake enhanced with hello extensions and supplemental data must proceed as described in section 5.1.
3. The server must require the client authentication during the handshake by sending the **CertificateRequest** message. According to [3], the server can provide a list of accepted certification authorities (CAs); in this case, the client must choose a certificate issued by one of these CAs. Because the client self-generates a new certificate for each TLS connection, the server must send the **CertificateRequest** message with the field **certificate_authorities** empty; therefore, according to [3], the client may send any certificate.
4. The client must DAA-sign the certificate used for TLS client authentication. This provides the binding between the TLS session and the DAA authentication and complete the client group authentication. The DAA signature must be sent to the server through the **SupplementalData** message while the self-signed client certificate must be sent to the server through the **Certificate** message.

The DAA protocol may also be used to sign other data, in addition to the self-signed client certificate used for the TLS authentication. This data, if present, depends on the context of the application. The input of the DAA-signing function must be

SHA1 (TLS_Client_Certificate || AdditionalData)

where **SHA1** is the digest calculation using SHA-1 [10] algorithm, **TLS_Client_Certificate** is the self-signed certificate used for the TLS authentication and DER-encoded, **||** is the concatenation operator and **AdditionalData** represents any additional data the application wants to DAA-sign.

An example of possible **AdditionalData** to DAA-sign is an Attestation Identity Key (AIK) which can be used for a remote attestation of the configuration of the platform; in this case the AIK must be signed by the DAA to convince the verifier that the AIK was generated and is used by a genuine TPM. This document neither defines the encoding of **AdditionalData** nor how it is created, but this might be specified in future documents.

If no additional data is present, the input of the DAA-signing function must be:

SHA1 (TLS_Client_Certificate)

If any additional data is DAA-signed together with the self-signed certificate on the client side, the server must be informed through the hello extension in order to be able to recompute the digest and verify the signature; any additional data DAA-signed must be transported within the supplemental data message so that it is possible for the verifier to recompute the signed digest.

5.4 Verification of the authentication

The server must verify the authentication of the client. This must be done by combining the different data exchanged during the handshake.

First, the server needs the verification of the correctness of the DAA signature. Besides, once the DAA signature is verified, it is necessary to verify the binding between the TLS session and the DAA authentication. In order to do this, the server must verify that the digest signed by the client corresponds to the digest calculated over the data exchanged during the TLS handshake. This is done by repeating on the server side the operations previously done on the client side: concatenating the self-signed certificate received from the client through the **Certificate** message with the additional data, if present, received from the client through the **SupplementalData** message and computing the digest over these composed data.

Since the **SupplementalData** message is sent from client to server before the **Certificate** message, the described verification can be done only after receiving the latter message. Moreover, according to [5], for security reasons the data exchanged as supplemental data must not have any effect on the handshake and must be evaluated only after its completion. Therefore the complete verification of the authentication must be performed only once the handshake is completed and the server must not accept any data from the TLS channel before the verification is finished and successful. If the verification fails the server must shut down the TLS channel.

5.5 Definition of the hello extension DAAAuth

This document specifies the **DAAAuth** hello extension according to [4]. This extension indicates the intention to use the DAA authentication of the TLS client. When sent by the latter, it means that the client supports the DAA authentication and wants to use it for authenticating itself; when it is sent by the server (only as response to the client), it means that the server agrees on using DAA authentication for the client.

This extension is defined as:

```
enum {
   DAAAuthExt (XX)
} ExtensionType;


struct {
     ExtensionType extension_type;
     opaque extension_data<0..2^16-1>;
} Extension;
```

where the type (**XX**) of the extension must be assigned by the IANA through the IETF Consensus process (see section 8 for details). The **extension_data** is defined as:

```
struct {
   DAAAuthVersion          daa_auth_version;
   DAAAuthParam            daa_auth_param <0..2^7-1>;
```

```
} DAAAuthExt;

struct {
   uint8 daatls_version, daa_binding_version;
} DAAAuthVersion;

struct {
   uint8   daa_auth_param_type;
   opaque  daa_auth_param_data <0..2^8-1>;
} DAAAuthParam;
```

where **DAAAuthVersion** is the version of the DAA authentication method used to enhance TLS and **DAAAuthParam** is a list that contains the parameters needed for the DAA authentication method. **daatls_version** specifies the version of the DAA-enhancement of TLS and indicates the set of the **DAAAuthParam** to exchange and in which sequence as well as the **DAAAuthReply** within the **SupplementalDataEntry**. A DAA-enhancement conforming to this specification is identified by the value 1. **daa_binding_version** indicated a specific binding (i.e. profile) for which includes a standardized specification of DAA (like the one proposed by TCG) and the specific relations with the DAA enhancements, including the data encoding and optionally software interfaces to be used. Each parameter is defined by a type and a payload and must appear at most once in the list:

```
enum {
   additional_data_sign (0),
   nonce (1),
   basename (2),
   (255)
} daa_auth_param_type;

struct {
   uint8   daa_auth_param_type;
   select (daa_auth_param_type) {
      case additional_data_sign: AdditionalDataSign;
      case nonce: Nonce;
      case basename: Basename;
   }
} DAAAuthParam;

struct {
   uint8   additional_data_is_present;
} AdditionalDataSign;

struct {
   uint8 nonce_length;
   opaque nonce <0..2^8-1>;
} Nonce;

struct {
```

```
    uint8 basename_length;
    opaque basename <0..2^8-1>;
} Basename;
```

The semantic of the different parameters which can be carried by **daa_auth_param_data** is defined as follows:

- **AdditionalDataSign** indicates that the client will also sign other data in addition to the certificate used for TLS authentication as described in section (5.2). This parameter can only be sent by the entity that makes the DAA signature and implies that some additional data must be transported within the supplemental data message. This is an optional parameter. When present, the additional_data_is_present field must be set to 1.
- **Nonce** is a DAA's own parameter, the nonce that the client must use during the DAA signature. This parameter must be always sent by the server (i.e. the DAA verifier).
- **Basename** is a DAA's own parameter, the basename that must be used during the DAA signature. If the server wants the client to have a pseudonymous, then this parameter must be present in the **DAAAuth** server hello extension. If the server wants the client to be completely anonymous, then the server must not send the basename in its **DAAAuth** hello extension: at the signature time the client must then use a randomly generated basename; the client must not ever send the basename in its **DAAAuth** hello extension.

5.6 Definition of the supplemental data entry DAAAuth

This document specifies the **DAAAuth** supplemental data entry, exchanged within the supplemental data message, according to [5].

The supplemental data entry must transport all data needed by the server to verify the DAA signature performed by the client; therefore, if negotiated, it must only send by client to server and never in the opposite direction.

The structure of the supplemental data entry for DAA authentication is defined as:

```
enum {
    DAA_auth_suppl_data_entry (XX)
}  SupplementalDataType;


struct {
    SupplementalDataType supp_data_type;
    uint16 supp_data_length;
    select(SupplementalDataType) {
       case  DAA_auth_suppl_data_entry: DAAAuthSupplDataEntry;
    }
} SupplementalDataEntry;
```

where the type (**XX**) of the supplemental data entry must be assigned according to [5] (see section 8 for details). The payload of the supplemental data entry, **DAAAuthSupplDataEntry**, is defined as:

```
struct {
```

```
    DAAAuthVersion          daa_auth_version;
    DAAAuthReply            daa_auth_reply <0..2^7-1>;
} DAAAuthSupplDataEntry;

struct {
    uint8   daa_auth_reply_type;
    opaque  daa_auth_reply_data <0..2^8-1>;
} DAAAuthReply;
```

where **DAAAuthVersion** indicates the version of the DAA-enhancement and identifies the binding with a DAA protocol specification (see section 5.5) and **DAAAuthReply** is a list that contains the data needed for authentication. In particular **daa_auth_reply_type** indicates the type of the data and can be defined as:

```
enum {
    daa_signature (0),
    signed_digest (1),
    additional_data_signed (2),
    (255)
} daa_auth_reply_type;

struct {
    uint8   daa_auth_reply_type;
    select (daa_auth_reply_type) {
        case daa_signature: DAASignature;
        case signed_digest: SignedDigest;
        case additional_signed_data: AdditionalSignedData;
    }
} DAAAuthReply;

struct {
    uint8 daa_signature_length;
    opaque daa_signature <0..2^8-1>;
} DAASignature;

struct {
    uint8 daa_signed_digest_length;
    opaque daa_signed_digest <0..2^8-1>;
} SignedDigest;

struct {
    uint8 daa_additional_signed_data_length;
    opaque daa_additional_signed_data <0..2^8-1>;
} AdditionalSignedData;
```

where **DAASignature** contains the DAA signature whose encoding depends on the value of **daa_binding_version** and it is specified accordingly while **SignedDigest** contains the SHA-1 digest actually DAA-signed. **AdditionalSignedData** contains the additional signed data and its presence and encoding must be negotiated through the

DAAAuth hello extension.

6 Specification of TCG TSS/TPM DAA profile for DAA-TLS

To have a complete specification for DAA-TLS it is necessary to define a DAA profile, i.e. a specific design and data format for DAA; therefore each profile must refer to a specific version of DAA protocol, standardized through a specification. The profile is build upon such base specification and must defines the (sub)set of features defined in the base specification to use for DAA-TLS, data encoding/decoding, interactions with APIs (if any), and any other aspect relevant to have a complete and interoperable specification for DAA-TLS. Depending on the features selected from the base specification, when defining a new DAA profile, it might be necessary to add new types for **DAAParam** and **DAAReply** respectively, thus leading to a new version of DAA-TLS.

In this section a DAA profile based on TCG TSS [2] and TPM [1] specifications is defined for the DAA-enhanced TLS protocol specified in Section 5. This profile is identified by the value 1 to assign to **daa_binding_version** carried by a **DAAParam**.

6.1 Profile requirements and specification

This profile specifies that all functions and data structures related to the attributes of DAA credentials and the Anonymity Revocation Authority (ARA) defined by TSS specification [] must not be used with DAA-TLS. Future versions of this DAA profile may specify the use of such features.

This profile requires a TCG-enabled platform for the TLS client (assuming the *platform* DAA role) equipped with a TPM 1.2 [1] and a TCG Software Stack (TSS) version 1.2 Errata A [2], while the TLS server (assuming the *verifier* DAA role) must only have installed the TSS with the same version as the client.

This profile define a list of the TSS functions required for DAA-TLS; for each one, the function prototype and a summary are included.

This profile also defines the data encoding/decoding rules.

Both the DAA-TLS handshake messages and the interactions (i.e. the function calls) with the TSP Interface exposed by TSS are shown in the combined diagram of Figure 4.

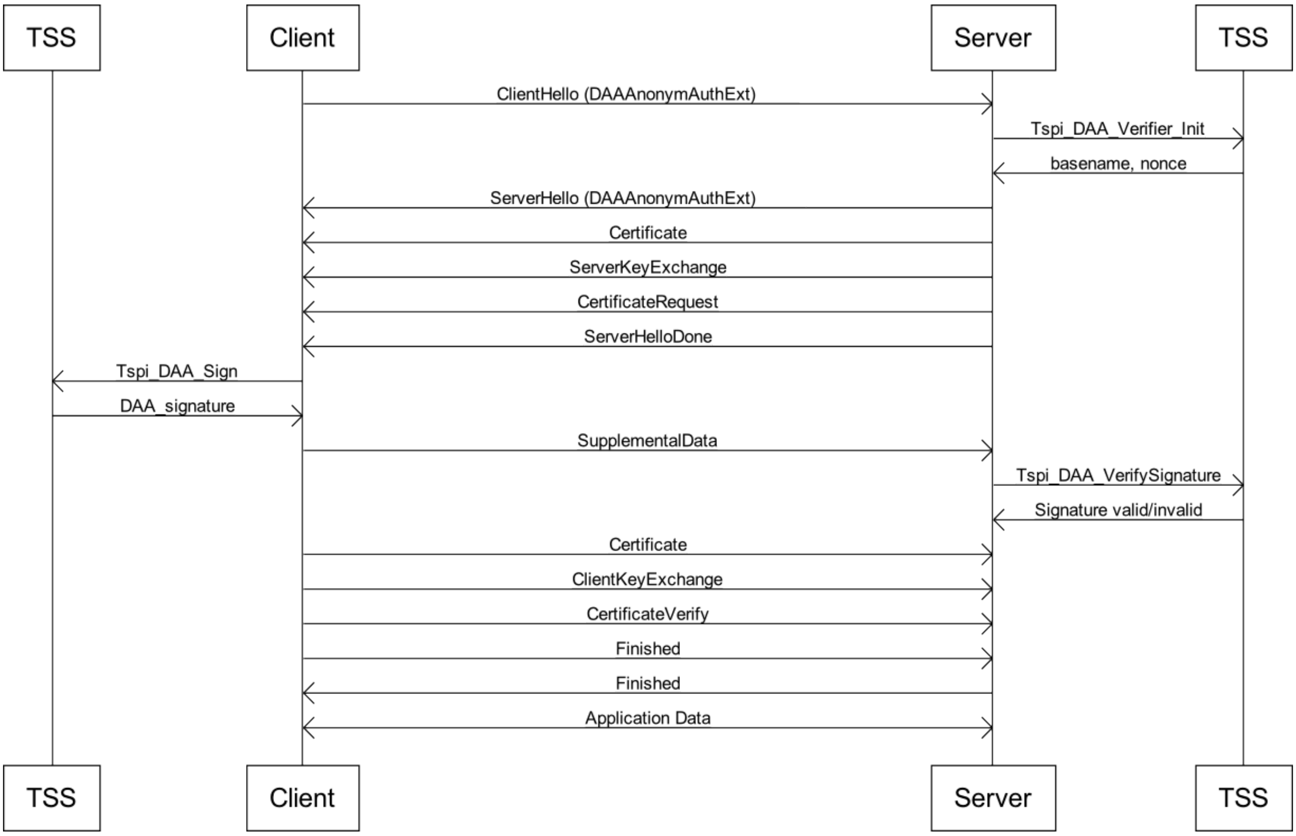

Figure 4: TCG TSS/TPM DAA profile for DAA-TLS: TLS handshake and TSS calls

6.2 Prerequisites for using TSS functions for DAA-TLS

The TSP Interface (TSPI) provided by TSS, exposes objects whose instances can be referenced through handles. Therefore before using an object it is necessary to create it and obtain the related handle; this can be done using specific functions provided by TSPI: this profile does not specify which functions must be used: refer to the TSS specification [2]. For this DAA profile, the necessary objects are:

- TPM object that allows to use the chip functionalities
- An object that contains information about the DAA issuer
- DAA credentials

Furthermore DAA-TLS requires that the platform (i.e. the TLS client) receives DAA credentials from a DAA issuer. This aspect is not covered in this document and it is supposed that such credentials are available on the client before the DAA-TLS handshake begins.

6.3 Nonce generation and basename

The nonce and the basename must be generated by the server and sent to the client via server hello extension; they must obtained by calling the TSS function

```
TSS_RESULT Tspi_DAA_Verifier_Init
     (
```

```
        TSS_HDAA_CREDENTIAL        hDAACredential,       // in
        UINT32*                    nonceVerifierLength,  // out
        BYTE**                     nonceVerifier,        // out
        UINT32*                    baseNameLength,       // out
        BYTE**                     baseName              // out
    );
```

where the first parameter is the handle of the DAA credential; the other parameters constitute the output of the function and represent respectively the size of the nonce, the nonce, the size of the basename and the basename.

The nonce must be sent to the client as **Nonce** as element of the list of **DAAParam** carried over the **DAAAuth** server hello extension.

If the basename is not returned by the function (i.e. ***baseNameLength** is set to 0 and ****baseName** to NULL), then the **Basename** must be not present as element of the list of **DAAParam** carried over the **DAAAuth** server hello extension.

6.4 DAA signature

The client must generate the DAA signature over the self-signed TLS client certificate and optionally over additional data; the signature must be sent to the server via supplemental data entry. The signature is generated by calling the TSS function

```
TSS_RESULT Tspi_TPM_DAA_Sign
(
    TSS_HTPM                   hTPM,                     // in
    TSS_HDAA_CREDENTIAL        hDAACredential,           // in
    TSS_HDAA_ARA_KEY           hARAKey,                  // in
    TSS_HHASH                  hARACondition,            // in
    TSS_DAA_SELECTED_ATTRIB*   revealAttributes,         // in
    UINT32                     verifierNonceLength,      // in
    BYTE*                      verifierNonce,            // in
    UINT32                     verifierBaseNameLength,   // in
    BYTE*                      verifierBaseName,         // in
    TSS_HOBJECT                signData,                 // in
    TSS_DAA_SIGNATURE**        daaSignature              // out
);
```

where the parameters are:

- **hTPM** is the handle of the TPM object
- **hDAACredential** is the handle of the object holding the DAA credential
- **hARAKey** is the handle of the Anonymity Revocation Authority (ARA) object. If it is NULL, then ARA is not used. This profile requires this parameter set to NULL
- **hARACondition** is the handle of the object indicating the conditions under which ARA should reveal the pseudonym. This must be NULL if **hARAKey** is NULL. This profile requires this parameter set to NULL
- **revealAttributes** represents the attributes the credential owner wants to reveal to the DAA verifier. This profile requires this parameter set to NULL

- **verifierBaseName** and **verifierBaseNameLength** are the respectively basename and its length. The basename must be set to the value received by the client as **Basename** as element of the list of **DAAParam** carried over the **DAAAuth** server hello extension. If **Basename** was not present as element of the list of **DAAParam**, then **verifierBaseName** must be set to NULL and **verifierBaseNameLength** must be set to 0
- **verifierNonce** and **verifierNonceLength** are respectively the nonce and its length. The nonce must be set to the value received by the client as **Nonce** element of the list of **DAAParam** carried over the **DAAAuth** server hello extension.
- **signData** is the handle of the object containing data to be DAA-signed to bind the TLS session to the DAA authentication; the type of the handle must be **TSS_HHASH**; the data carried by the object must be the digest calculated using SHA-1 algorithm over the self-signed TLS client certificate (DER-encoded) and, if present, additional data. The details of this calculation are specified in section 5.3. The output of the calculation must be used to instantiate the object referenced by **signData** and must also be sent to the server as **SignedDigest** (together with the additional data, if any, as **AdditionalSignedData** element of the list of **DAAReply** carried over the **DAAAuth** supplemental data entry
- **daaSignature** is the output of the function, i.e. the DAA signature performed by TSS/TPM with the credential handled by **hDAACredential**, over **SignData** using the nonce received from the server and the basename either received from the server or randomly generated by the client itself at the signature time. **DaaSignature** must be sent to the server as **DAASignature** element of the list of **DAAReply** carried over the **DAAAuth** supplemental data entry

6.5 Signature verification

The server must verify the DAA signature received from client through the supplemental data. The signature is verified by calling the TSS function

```
TSS_RESULT Tspi_DAA_VerifySignature
(
     TSS_HDAA_CREDENTIAL        hDAACredential,            // in
     TSS_HDAA_ISSUER_KEY        hIssuerKey,                // in
     TSS_HDAA_ARA_KEY           hARAKey,                   // in
     TSS_HHASH                  hARACondition,             // in
     UINT32                     attributesLength,          // in
     UINT32                     attributesLength2,         // in
     BYTE**                     attributes,                // in
     UINT32                     verifierNonceLength,       // in
     BYTE*                      verifierNonce,             // in
     UINT32                     verifierBaseNameLength,    // in
     BYTE*                      verifierBaseName,          // in
     TSS_HOBJECT                signData,                  // in
     TSS_DAA_SIGNATURE*         daaSignature,              // in
     TSS_BOOL*                  isCorrect                  // out
);
```

where the parameters are:

- **hDAACredential** is the handle of the object holding the DAA credential

- **hIssuerKey** is the handle of the object holding the issuer public key
- **hARAKey** is the handle of the Anonymity Revocation Authority (ARA) object. If it is NULL, then ARA is not used. This profile requires this parameter set to NULL
- **hARACondition** is the handle of the object indicating the conditions under which ARA should reveal the pseudonym. This must be NULL if **hARAKey** is NULL. This profile requires this parameter set to NULL
- **attributesLength**, **attributesLength2** and **attributes** are respectively the number of attributes revealed by the owner of the DAA credential, the size in bytes of each attribute and the list of the revealed attributes. This profile requires the first two parameters set to 0 and the last one set to NULL
- **verifierBaseName** and **verifierBaseNameLength** are respectively the basename and its length used for the signature. If the function **Tspi_DAA_VerifyInit** previously called by the server returned a basename, then **verifierBaseName** and **verifierBaseNameLength** must be set to corresponding values returned by **Tspi_DAA_VerifyInit**. Instead, if the latter returned NULL, then **verifierBaseName** and **verifierBaseNameLength** must be set to the basename randomly chosen by the client and sent to the server as **Basename** element of the list of **DAAReply**, carried over the **DAAAuth** supplemental data entry
- **verifierNonce** and **verifierNonceLength** are respectively the nonce and its length used for the signature and must be set to the corresponding values returned by the function **Tspi_DAA_VerifyInit** previously called by the server
- **signData** is the handle of the object containing data DAA-signed by the client to bind the TLS session to the DAA authentication; the type of the handle must be **TSS_HHASH**; this object must be created with using the data received from the client as **SignedDigest** element of the list of **DAAReply** carried over the **DAAAuth** supplemental data entry
- **daaSignature** is the actual signature to be verified, received by the client as **DAASignature** element of the list of **DAAReply** carried over the **DAAAuth** supplemental data entry
- **isCorrect** is the function output and indicates if the verification of the DAA signature was successful

6.6 Data encoding/decoding

6.6.1 Basic data types

According to [2], Section 4.3.4.29.10, all DAA-related data structures used as input/output to/from TSS are encoded with the big endian (or network order byte) format, with the Most Significant Byte at the far left of a multi-byte data unit (e.g. buffer or word) and th Least Significant Byte at the far right. Since data structures can contain other embedded structures but are at the end made up of elementary data, also the latter are encoded with the big endian format

According to [3], Section 4, all data types defined using the Presentation Language for TLS (like **DAAAuth** hello extension and supplemental data entry) and holding multi-byte values are encoded with the big endian (or network order byte) format.

Therefore converting elementary data as buffers or words from/to TSS encoding to/from TLS encoding does not require any adaptation of the order byte but only, if necessary, the adjustment of the length in bytes.

6.6.2 Complex types

6.6.2.1 DAA Signature (normative)

The DAA Signature, sent by the server as **DAASignature** element of the list of **DAAReply** carried over the **DAAAuth** supplemental data entry, must be BER-encoded according to the ASN.1 definition of the Portable Data specified in the following. Each member of the TSS structure must be individually re-encoded to BER and vice versa. If the member is not an elementary data, it must be recursively expanded until all elementary data are exposed: then they can be re-encoded as the corresponding members for the target encoding rules.

```
DaaSignature ::= SEQUENCE
{
     versionInfo                 TssVersion,
     zeta                        INTEGER,      -- z
     capitalT                    INTEGER,      -- T
     challenge                   OCTET STRING,  -- 20 bytes long
     nonceTpm                    OCTET STRING,  -- 20 bytes long (vrfy)
     sV                          INTEGER,     -- sV
     sF0                         INTEGER,     -- sF0
     sF1                         INTEGER,     -- sF1
     sE                          INTEGER,     -- sE
     sA                          INTEGER,     -- sA
     attribCommitSequence        AttribCommitSequence,
     tssDaaPseudonym             TssDaaPseudonym,
     tssDaaSignCallback          TssDaaSignCallback
}

TssVersion ::= SEQUENCE
{
     major                       INTEGER,
     minor                       INTEGER,
     revMajor                    INTEGER,
     revMinor                    INTEGER
}

AttribCommitSequence ::= SEQUENCE SIZE (0..MAX) OF TssDaaAttribCommit

TssDaaAttribCommit ::= SEQUENCE
{
     versionInfo                 TssVersion,
     beta                        INTEGER,
     sMu                         INTEGER
}
```

```
TssDaaPseudonym ::= SEQUENCE
{
     versionInfo                 TssVersion,
     payloadFlag                 INTEGER,      -- TSS_FLAG (uint32)
     payload                     OCTET STRING  -- (verify)
}

TssDaaSignCallback ::= SEQUENCE
{
     versionInfo                 TssVersion,
     challenge                   OCTET STRING, -- 20 bytes long
     payloadFlag                 INTEGER,      -- TSS_FLAG (uint32)
     payload                     OCTET STRING  -- (verify)
}
```

7 Security considerations

7.1 Endorsement Key (EK) exposure

TCG design ([1,2]) of DAA protocol gives the verifier assurance about the genuineness of the TPM making DAA signatures. By issuing the DAA credentials, the issuer guarantees that the TPM is genuine.

To enforce this behavior, once the issuer verified the credentials (e.g. EK certificate) provided by the platform requesting a DAA credential, the issuer creates the latter and encrypts it with the public part of the Endorsement Key (EK) of the TPM requesting the credential. This procedure guarantees that TPM owning the private part of the Endorsement Key can decrypt, install and use the received DAA credential.

This procedure has the drawback that the issuer gets to know the public part of the EK: being unique to every TPM, the EK can be used as a identifier to track TPM operations that involves the EK (i.e. requesting other DAA credentials or an AIK certificate). For this reason, the issuer must be a trusted third party that guarantees to the verifier that the genuineness of the TPM is checked and to the platform the sensitive data (i.e. the public part of the EK) are kept secure.

While this is not a problem in the reference scenario (where the company is the issuer), it may become a problem in more open scenarios; in these latter cases, the platform must carefully choose the DAA issuer.

7.2 Basename and DAA signature

In some scenarios, the basename or the DAA signature may be considered sensitive data. For instance, a man in the middle can forge the basename by modifying the server hello message. In this case it can persuade the client to make a DAA signature over a chosen basename. If the basename was chosen to be fixed, it is possible for the attacker to track successive DAA signatures of the same platform over the same basename.

The TLS protocol allows both the client and the server to detect the attack, but only after the DAA signature was made. This attack can be detected when the finished messages are exchanged: these messages are a hash of all the messages exchanged during the handshake; if the attacker modified the server hello, the server will compute a hash different from the hash computed by the client, leading to the discover of the attack.

Furthermore, by listening to the channel in the case of a pseudonymous authentication, an eavesdropper could be able to link together different DAA signature made by the same platform. Listening the channel leads the attacker to know both the basename and the DAA signature; in the case of pseudonymity, these two data are enough to link different signatures made by the same platform. Differently from the previous attack, this attack can not be detected by the client nor the server and, hence, it puts at risk the privacy of the client.

For these reasons in some scenarios, the data exchanged within the supplemental data message must be protected. [5] asserts that such protection must be provided through the use of a double handshake. The first handshake is a regular one that only aims to the creation of a secure channel. Next, within the secure channel a second handshake happens; this latter handshake carries the hello extensions and the supplemental data necessary for the anonymous authentication.

Note that in the case of a double handshake, the first handshake must be done in a way that exposes no information about the peer that must be authenticated anonymously using the DAA in the second handshake.

8 IANA considerations

The hello extensions and the supplemental data entries are defined by their types. The hello extensions types MUST be assigned by the IANA through a IETF consensus procedure, while the supplemental data specification allows the use of private types for the supplemental data entries.

Because each supplemental data entry MUST be negotiated using the hello extensions mechanism, it is not actually possible to use the private types for the supplemental data entry defined in this document.

For this reason this document does not defines the types of the hello extension nor the type of the supplemental data entry.

9 List of abbreviations

Listing of term definitions and abbreviations used in this document (IT expressions and terms from the application domain).

Abbreviation	Explanation
AIK	Attestation Identity Key
ARA	Anonymity Revocation Authority
ASN.1	Abstract Syntax Notation 1
BER	Basic Encoding Rules
CA	Certification Authority
DAA	Direct Anonymous Attestation
DER	Distinguished Encoding Rules
EK	Endorsement Key
SHA-1	Secure Hash Algorithm 1
TCG	Trusted Computing Group
TLS	Transport Layer Security
TPM	Trusted Platform Module
TSS	TCG Software Stack

10 Referenced Documents

/1/ TCG TPM Main Specification (parts 1,2,3)
July 9, 2007,
Version 1.2 Level 2 Revision 103

/2/ TCG Software Stack (TSS) Specification
March 7, 2007,
Version 1.2, Level 1, Errata A

/3/ IETF RFC 4346, The Transport Layer Security (TLS) Protocol Version 1.1
April, 2006

/4/ IETF RFC 4366, Transport Layer Security (TLS) Extensions
April, 2006

/5/ IETF RFC 4680, TLS Handshake Message for Supplemental Data
September, 2006

/6/ Direct Anonymous Attestation
Ernie Brickell, Jan Camenisch, Liqun Chen
CCS '04: 11th ACM conference on Computer and Communications Security
2004

/7/ ITU-T Rec. X.208, Specification of Abstract Syntax Notation One (ASN.1)
1988

/8/ ITU-T Recommendation X.690, Information Technology – ASN.1 encoding rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and

Distinguished Encoding Rules (DER)
1997

/9/ ITU-T Recommendation X.509, Information technology – Open Systems Interconnection – The Directory: Public-key and attribute certificate frameworks

/10/ IETF RFC 3174, US Secure Hash Algorithm 1 (SHA1)
September, 2001

WP03c.4 Key Management Adaptation (KMA) service source code and documentation

Project number	IST- 027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Internal document

Deliverable reference number	IST-027635/D03c.4/FINAL 2.00
Deliverable title	Key Management Adaptation (KMA) service source code and documentation
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Due date	May 2007 - M19
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Responsible Organisation	Politecnico di Torino
Authors	Gianluca Ramunno and Roberto Sassu (POL)
Abstract	Key and data Management Adaptation layer (KMA), formerly "High-level Key Manager service", is intended to be a software system built upon TPM and TSS, whose goals are protecting keys and other sensitive data for generic applications and services and binding the access to the protected information to the integrity of the system. This document describes the procedures for building, installing and configuring KMA version 0.1.0.
Keywords	Open_TC, KMA, TPM, TSS

Dissemination level	Public
Revision	FINAL 2.00

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

Table of Contents

1 Introduction

Key and data Management Adaptation layer (KMA), formerly "High-level Key Manager service", is a software system built upon TPM [1] and TSS [3], whose goals are protecting keys and other sensitive data for generic applications and services and binding the access to the protected information to the integrity of the system.

Specific objectives for KMA are:

- access to protected data granted only if the integrity of system and the application/service requiring the access are verified
- (optional) access to protected data granted only if the system and the application/service have specific values for selected run-time properties (e.g. the user currently logged in)
- isolation between protected data of different applications/services at run-time to prevent that, if an application gets compromised (e.g. because of a flaw) and the protected data can be accessed in memory by an attacker, the protected data of all other applications/services can be accessed by the attacker
- data protection robust against off-line attacks to the storage device
- generic protection mechanism for data files that does not require any modification to the application/service at build time, in order to use KMA with standard distributions
- support for the access to TPM keys bound to system/application integrity and properties, requiring minimal modifications at build time for application directly using the TPM keys
- seamless upgrade of the operating system and the protected applications while keeping the data protection
- support for platforms with a single operating systems running or (optionally) full virtual machines

This is the companion document for `D03c.4_KMA_source_code_and_RPMS.zip`, the tarball including source code and binary RPM packages. This document describes the procedures for building, installing, configuring KMA version 0.1.0 and testing the secured version of OpenSSH, an implementation of SSH [2] protocol.

With respect to the high-level specification document [4], this first version of KMA is a proof of concept. The storage manager is implemented completely in user memory space for faster prototyping. In future versions, the components of the storage manager dealing with sensitive data will be moved to the kernel memory space. Currently, in addition to the "application" credential, only the "user" credential is supported and the selection of one or both credentials is currently hard-coded for ssh and sshd. In future versions this aspect will be easily configurable for each application to be secured. Currently only the main executable file is certified while the shared libraries are not taken into account; in future versions all shared libraries an application depends on will be also certified. Finally, with the current version of KMA the applications to be secured must be slightly modified and rebuilt while in future versions a secured application will not require any modification at build time.

2 Building and installing KMA

2.1 Important notes (to read carefully before building or using KMA)

The version 0.1.0 of KMA is the first one made available to the OpenTC consortium. It is still a proof of concept prototype: in order to test it a single bundle is provided also including a preconfigured secured application, namely a modified version of OpenSSH (providing ssh and sshd). The main differences between this proof of concept prototype and the requirements stated in [4] are presented in the introduction of this document.

KMA version 0.1.0 includes patches applied to the Linux kernel and it requires the installation of the boot loader TrustedGRUB which may result in a platform not booting anymore, if something fails. The passwords in this version are input in clear text. KMA has not been deeply tested yet and in particular stress tests or tests about concurrent use of KMA other than a pair of ssh/sshd applications at the same time have not yet been performed.

For all aforementioned reasons, KMA version 0.1.0 must be considered as preliminary and experimental software: it should not be installed on platforms in production while it should be only installed on testing platforms by experienced users.

2.2 Introduction

KMA version 0.1.0 is distributed in two forms:

- a tarball `pol-kma-sources.tar.bz2` including source code and scripts for building
- a tarball `pol-kma-rpms.tar.bz2` including RPM packages with binaries only for direct installation

Both have to be extracted from the tarball `D03c.4_KMA_source_code_and_RPMS.zip` associated to this document.

Two procedures will be specified:

- building RPMs packages with binaries from the source tarball and installing KMA from the newly generated RPM packages
- installing KMA directly from the provided RPM binary packages

Before installing KMA packages, some prerequisites must be met. To build KMA there are also additional requirements. In the following subsection all prerequisites are listed, indicating whether they are required for installing only or also for building.

2.3 KMA package dependencies (prerequisites)

The prerequisites are mostly expressed in terms of software packages to be installed. For each package (or group of packages), it is indicated if the package is required when *building* KMA or when *installing* it.

2.3.1 Prerequisites

- a hardware platform with TPM 1.1 or 1.2 and ownership correctly taken;

currently it has been tested only on HP Compaq nw8000 and HP dc7700 platforms (*installing*)

- a specific Linux distribution and version installed, `openSUSE 10.3`, with a specific SUSE Linux kernel, version `2.6.22-17`: with future versions of the Linux kernel KMA v 0.1.0 might not work (*building*, *installing*)
- superuser privileges, i.e. access to `root` account (*building*, *installing*)
- packages required for kernel development (gcc, make, etc.) (*building*)
- kernel (`kernel-source`) and OpenSSH (`openssh`) source packages (*building*)
- `makedumpfile` (*building*)
- `fuse-devel` (*building*)
- `wget` (*building*)
- `audit-devel` (*building*)
- `krb5-devel` (*building*)
- `opensc-devel` (*building*)
- `tcpd-devel` (*building*)
- `createrepo` (*building*)
- `trousers-devel`[1] (*building*, *installing*)
- `trusted-grub`[2] (*installing*)

The installation of openSUSE 10.3 can be done using an off-line distribution medium (i.e. CDs or DVD). Then connecting the platform to a network allowing surfing the Internet is recommended (required at least to install `trousers-devel` and `trusted-grub` which are not included in the standard distribution media).

An on-line system update is recommended before building or installing KMA. Then the OpenTC @SUSE repository for RPM packages must be added to the Yast configuration.

2.3.2 Adding OpenTC repository via zypper

This can be done with the following console command:

- `zypper addrepo -t rpm-md http://download.opensuse.org/repositories/security:/OpenTC/openSUSE_10.3/ OpenTC`

2.3.3 Adding OpenTC repository via Yast (alternative procedure)

An alternative procedure for installing KMA can be performed using Yast from console[3]. Yast can be started via console command:

1 available from the OpenTC opensuse repository reachable at the address: `http://download.opensuse.org/repositories/security:/OpenTC/openSUSE_10.3/`

2 available from the OpenTC opensuse repository reachable at the address: `http://download.opensuse.org/repositories/security:/OpenTC/openSUSE_10.3/`

3 a similar sequence can be performed using the GUI version of Yast, which can be started by `Menu Computer -> Control Center -> Yast -> Software Repositories` for adding a new repository

```
yast
```

then select `Software -> Software repositories -> Add -> HTTP`. Then fill in the field “Server Name” with:

```
download.opensuse.org
```

and the field “Directory on Server” with:

```
/repositories/security:/OpenTC/openSUSE_10.3/
```

2.3.4 Installing required packages (prerequisites)

Now the packages previously listed can be installed.

The packages with the source code (required only for *building*) can be installed by executing the console command:

```
zypper source-install kernel-source openssh
```

The other packages (with the binaries) can be installed by executing the console command:

```
zypper install <package> <package> ...
```

where `<package>` is each one of the listed packages according to the requirements (*building* and/or *installing*)

While installing the listed packages, if they depend on additional packages, also the latter are automatically installed.

2.3.5 KMA building procedure

2.3.5.1 Building from the source tarball

1. Copy the distributed tarball with source code (`pol-kma-sources.tar.bz2`) to a temporary directory (`TEMPDIR`, where “`TEMPDIR`” **is a full path including the root “/” of the file system**), enter this directory and extract the content from the tarball with the following command;

   ```
   tar jzvf pol-kma-sources.tar.bz2
   ```

2. Check the configuration of the script `buildkma` by editing the file `buildkmasettings` in the directory `TEMPDIR/pol-kma`; for a default build nothing should be done and this step can be skipped;
3. Check the list of the packages that will be built by editing the file `buildkmadb` in the directory `TEMPDIR/pol-kma`; for a default build nothing should be done and this step can be skipped;
4. Execute `./buildkma --source=tarballs` to start the build process. It may takes a long time (up to few hours depending on the platform) and 4-5 GB of free space on the hard disk are required;
5. If the building procedure stops because the creation of `pol-kma-userspace-apps` package fails (for a problem with package dependencies), then the following procedure must be executed. One package just generated and required to build the next one must be manually installed with the following

command:

```
rpm -Uhvi --nodeps ./packages/RPMS/i586/kma-userspace-libs-devel-
0.1.0_initial-1.i586.rpm
```

Then execute again `./buildkma --source=tarballs`; this time the process should end successfully.

If the building procedure fails at some point it is possible to see the error occurred by viewing the file with the name of the package created in the `lastlog` directory.

2.3.5.2 Parameters defined in configuration file `buildkmasettings`

The following notes are only for experienced users and no parameter must be changed for a standard building procedure. Some parameters or commands refer to a SVN server which can host the source code for KMA: they can be ignored when building KMA from a source tarball.

- **PKGSUFFX**: indicates a directory, different from `/usr/src/packages/RPMS`, where the binary RPMs will be created;
- **PKGSRCSUFFX**: indicates a directory, different from `/usr/src/packages/SRPMS`, where the source RPMs will be created;
- **SVNADDRESS**: indicates the URL of a SVN server providing all KMA packages;
- **OWNREPO**: indicates an existent repository of RPMs: the script `buildkma` builds a package only if its current version on SVN is greater than the version for the same package present in the local and in the given repositories;
- **CREATEREPO**: indicates, if yes (default), that the command `createrepo` will be executed in the directory defined by the `PKGSUFFX` variable or in `/usr/src/packages/RPMS;` the command `createrepo` is used to make a directory suitable for package installation using YaST;
- **TARBALREP**: indicates a directory where the tarballs created before the RPM package creation procedure will be stored.

The script `buildkma` takes some command line parameters:

- **--fetch-only**: executes the command `svn checkout` for each package listed in the file `buildkmadb;`
- **--source=[svn,tarballs]**: selects the source repository for building RPM packages: it can be the `SVN` repository specified in the `SVNADDRESS` variable or the directory specified in the `TARBALREP` variable containing the tarballs with the source code;
- **--make-tarballs**: used with `--source=rpm` allows to create only the tarballs from the source code files freshly downloaded from the SVN repository (no RPM package generated).

The script `buildkma` downloads the required source files and creates the RPM for each package defined in the `buildkmadb` file and places them in the directory defined by the `PKGSUFFX` (if not empty) or in the `/usr/src/packages/RPMS` directory.

2.4 KMA package overview

The KMA software is formed by two groups of components: one group runs in kernel memory space while the other one in user memory space.

The components running in kernel memory space are installed through the **pol-kernel-kma** package and consist of:

- a modified Linux kernel with some KMA modules built-in:
  - **kmakeys**: Key Repository;
  - **kmauth-authority**: Authority for credentials management;
  - **kmauth-loader**: Linux Security Module that executes KMA functions when a process (of a secured application) is created or terminated;
- others kernel modules loaded at the bootstrap of the platform:
  - **kmauth-bootstrap**: KMA Bootstrap performs the initialization of KMA during the boot process, and requests the sealing/unsealing function to the TPM directly within the kernel;
  - **kmauth-ticket**: Ticket Manager, builds and transmits tickets through a device driver; used by TrouSerS during the authorization process for using TPM keys;

The components running in user memory space are installed through these packages:

- **pol-kma-userspace-libs**: contains the libraries used by the signing utility, the FUSE daemon, the KMAD daemon and a library that export a function called by the modified applications (i.e. the secured applications) like ssh and sshd;
  - */usr/lib/libkmauser.so*: used by KMAD, FUSE and the signing tool;
  - */usr/lib/libkmauserapp.so*: library linked with the modified applications.
- **pol-kma-userspace-apps**: contains the KMAD daemon that is used to activate the data repository bound to a secured application when it makes a request; the FUSE daemon whose instances manage each one a data repository at once;
  - */usr/sbin/kmad*: KMAD daemon;
  - */usr/sbin/kmafsd*: FUSE daemon.
- **pol-bsign-kma**: contains Binary Sign (bSign) a tool used to modify the ELF header of the binaries that will be certified in order to embed the certification;
  - */usr/bin/kma_start_sign*
  - */usr/bin/bsign*.
- **pol-openssh-kma**; contains a modified (i.e. secured) version of ssh and sshd;
  - */usr/bin/ssh*;
  - */usr/sbin/sshd*.

2.5 KMA installation guide

The requirements for installing KMA are listed in Section 2.3.

There are two ways to install KMA from the provided tarballs:

- directly from the tarball (`pol-kma-rpms.tar.bz2`) containing the RPM packages (this option does not require a previous build process); the distributed tarball must be expanded: copy it to a temporary directory (`TEMPDIR`, where "`TEMPDIR`" **is a full path including the root "/" of the file system**), enter this directory and extract the content from the tarball with the following command:

  ```
  tar jxvf pol-kma-rpms.tar.bz2
  ```

  the folder `TEMPDIR/pol-kma-rpms` will be created containing all RPM packages with the binaries
- from the RPM packages created after the building procedure performed using the tarball containing (`pol-kma-sources.tar.bz2`) the source code

2.5.1 Installation via zypper

In both cases it is necessary to add the path of the local repository containing the KMA packages with the following console commands:

- `zypper addrepo -t rpm-md file://TEMPDIR/pol-kma-rpms/ KMA`
  for direct installation from the provided RPM packages
- `zypper addrepo -t rpm-md file://TEMPDIR/pol-kma/packages/RPMS KMA`
  for installation from packages just built from the source tarball

Now the KMA packages can be installed with the following console command:

```
zypper install openssh_kma
```

all other packages will be automatically installed.

2.5.2 Installation via Yast (alternative procedure)

An alternative procedure for installing KMA can be performed using Yast from console[4]. Yast can be started via console command:

```
yast
```

then select `Software -> Software repositories -> Add -> Local Directory`. Then fill in the field "Path to Directory" with:

- `TEMPDIR/pol-kma-rpms` for direct installation from the provided RPM packages
- `TEMPDIR/pol-kma/packages/RPMS` for installation from packages just built from the source tarball

After having added the repository, without leaving Yast access the section `Software -> Software Management` section, then select the "`Repositories`" filter. By clicking on "`KMA`" repository, the Administrator can see all packages required for KMA to work.

The only action required is to select the package `openssh_kma`; all other packages will be automatically installed.

4 a similar sequence can be performed using the GUI version of Yast, which can be started by `Menu Computer -> Control Center -> Yast -> Software Repositories` for adding a new repository and `Menu Computer -> Control Center -> Yast -> Software Management` for installing new packages

2.6 KMA configuration

2.6.1 Step-by-step procedure

After having installed the packages with the root privilege, the following steps must be performed:

1. **Creating the file list /var/kma/data/kma_filelist**: this is the list of files that will be included in the configuration that will be enforced (via sealing/unsealing) at every platform bootstrap to make KMA start properly.

   NOTE: this file must be created by adding the files the administrator wants to use for sealing; for testing purposes this step can be skipped

2. **Configuring TrustedGRUB** (i.e. installing it onto the Master Boot Record or boot sector, only once): this can be done by starting
   grub
   setup <device>
   if openSUSE was installed on a the first (clean) hard disk, most likely <device> can be:
   (hd0)
   this step it must be executed by experienced and aware users;

3. **Rebooting the platform**: from the boot menu choose the following option:
   Kma – openSUSE 10.3 – 2.6.22.18-x

4. **Sealing against configuration**: a script executed in the initial ramdisk starts the sealing procedure:

   1. **Requesting the SRK password**: the KMA Administrator must decide if setting the Storage Root Key (SRK) or not; if set, this will be then asked at every bootstrap of the platform; a wrong input password will make KMA not operational.

   2. **Requesting the Admin password**: the KMA Administrator is required to choose a secret that will be used to certify the binaries with the bsign utility.

5. **Logging in**: as superuser (root)

6. **Certifying binaries**: the KMA Administrator logs in to the system and executes the command kma_start_sign. This causes, after the KMA Administrator inputs his secret, an automatic procedure to certify all binaries required by KMA to work propertly;

7. **Rebooting the platform**: from the boot menu choose the following option:
   Kma – openSUSE 10.3 – 2.6.22.18-x

8. **Unsealing against configuration**: when the system starts up the user must enter the SRK password (if previously set) in order to make KMA perform the unsealing operation. KMA executes the operation and displays the result. If not successful, KMA will not be operational;

9. **Securing and using application**: with this version of KMA, modified ssh and sshd are provided in bundle. The sshd application is automatically secured, via startup script; ssh must be started once, unprotected, and configured for using a RSA key for the client authentication. Then the user can test ssh secured by

KMA by giving the commands:

- `ssh -Kmakesecure <host>`: this makes the files `.ssh/id_rsa` and `.ssh/id_rsa.pub` be moved to a protected KMA repository only accessible by the secured application and replaced with symbolic links pointing to the protected files; after this phase the execution ends and `<host>` is ignored;
- `ssh -Ksecure <host>`: this makes the user able to connect to remote hosts using his private key which is never exposed to other applications; `<host>` can also be `localhost`, thus connecting to the KMA-protected sshd;
- `ssh -Kmakeinsecure <host>`: this makes the files protected by KMA be moved to their original location, thus restoring the configuration in place before the "securing" operation; after this phase the execution ends and `<host>` is ignored.

2.6.2 Other aspects

2.6.2.1 Usage of the `kma_start_sign` certification utility

During the normal use of openSUSE, some packages can be automatically updated (also KMA packages might require an upgrade): this operation results in files previously certified being replaced by new "uncertified" versions. Therefore, upon completion of updates involving secured applications or the bash shell, the KMA Administrator must execute the command `kma_start_sign` in order to certify the new versions of the binary files. It is responsibility of KMA Administrator verifying that the updated components still meet the desired security requirements.

If during normal operations some files are damaged or altered, secured applications may not be able to access their data repositories. The command `kma_start_sign` can be started to check the binaries and if it detects this issue, it interactively proposes two options. Either restoring the original binary file before the certification procedure or it proposes to replace the bad signature with a new one. In this case when the `kma_start_sign` requests the "Authority type", the KMA Administrator must use the type "1" for `/bin/bash`, the type "0" for all other binaries.

2.6.2.2 Recovering sealed data upon platform setting changes

If a platform component involved in the sealing phase is updated, like a file listed in `/var/kma/data/kma_filelist` or the `kernel`, the unsealing procedure performed at boot time will fail and KMA will not be activated.

The sealed data is the master key used by KMA to verify the certification of the binary files. Therefore, if the KMA Administrator starts a new sealing procedure, which implies the creation of a new master key, the binaries cannot be recognized anymore and all data files stored by secured applications are definitely lost.

However KMA supports a recovery procedure for the sealed data.

In this case the KMA Administrator must delete the file `/var/kma/data/blobfile`, which containing the sealed blob of the master key, and restart the platform.

During the boot phase the script in the initial ramdisk automatically detects that the sealed blob is missing and asks the KMA administrator to input the Admin password. Using this password, the script unlocks the copy of the master key bound to a TPM key (and normally used to certify the binaries) and seals the master keys against the current configuration.

After restarting the platform, KMA will be again operational and the secured applications will be able again to access their protected data.

Before starting the recovery procedure, it is responsibility of KMA Administrator verifying that the updated components still meet the desired security requirements.

2.6.2.3 Resetting the configuration of secured applications

If a secured application fails while reading its data files from the protected repository and the two aforementioned events (i.e. updates of components, either certified or involved in sealing) have not occurred, the KMA Administrator must create a new configuration for all data repositories: all data for all application will be lost: this is a limitation of the current version of KMA. To perform this action, the daemon `kmad` must be stopped and the file `/etc/kma/kmadb.db` must be deleted from the filesystem. Then the KMA Administrator can then restart the `kmad` daemon, which creates a new fresh and empty database for the protected storage of all secured applications.

3 List of Abbreviations

Listing of term definitions and abbreviations used in this document (IT expressions and terms from the application domain).

Abbreviation	Explanation
KMA	Key and data Management Adaptation layer
SRK	Storage Root Key
TCG	Trusted Computing Group
TPM	Trusted Platform Module
TSS	TCG Software Stack

4 Related Work

/1/ TCG TPM Main Specification (parts 1,2,3)
July 9, 2007,
Version 1.2 Level 2 Revision 103

/2/ IETF RFC 4251, The Secure Shell (SSH) Protocol Architecture
January, 2006

/3/ TCG Software Stack (TSS) Specification
March 7, 2007,
Version 1.2, Level 1, Errata A

/4/ OpenTC IST-027635/D03c.2/FINAL 2.00
High-level key manager service design specification
Version 2.00
June, 2008

D03c.5 OpenSSH adaptation service source code and documentation

Project number	IST- 027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Internal document

Deliverable reference number	IST-027635/D03c.5/FINAL 2.00
Deliverable title	OpenSSH adaptation service source code and documentation
WP contributing to the deliverable	WP3
Due date	Jul 2007 - M21
Actual submission date	Jun 2008 - M32 (revised version)

Responsible Organisation	Politecnico di Torino
Authors	Gianluca Ramunno and Roberto Sassu (POL)
Abstract	This document only describes the modifications applied to the source code OpenSSH to adapt it for KMA. The modified source code, the procedures for building, installing and configuring this KMA-enhanced version of OpenSSH are provided through the OpenTC deliverable: IST-027635/D03c.4/FINAL 2.00.
Keywords	Open_TC, KMA, TPM, TSS, SSH, OpenSSH

Dissemination level	Public
Revision	FINAL 2.00

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

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1 Introduction

This document only describes the modifications applied to the source code OpenSSH [1], an implementation of SSH [2] protocol to adapt it for KMA.

The modified source code, the procedures for building, installing and configuring this KMA-enhanced version of OpenSSH are provided through the OpenTC deliverable “Key Management Adaptation (KMA) service source code and documentation” [3]. Refer to the latter document for any detail about packages referenced in the following.

2 OpenSSH modifications for KMA

The source tarball `openssh_kma`, available when unpacking contains all required elements to patch the original source code available from the `openssh` source RPM package. To obtain `openssh_kma`, it is necessary first to unpack the main archive provided with [3], i.e. `D03c.4_KMA_source_code_and_RPMS.zip`, then take and unpack `pol-kma-sources.tar.bz2`.

If an experienced user wants to build the package manually, instead of using the procedure described in [3], first he must download the `openssh` source package from an `openSUSE` repository. Then he must apply the patches contained in the `patches` directory obtained by unpacking the tarball `pol-kma-sources.tar.bz2` and must start to compile it by executing the command `make`. After building the modified package, the user must install the binaries just built by executing the command `make install`. Lastly the user must replace the `openssh` init script with the one stored in the `others` directory of the expanded `pol-kma-sources.tar.bz2` tarball and named `sshd_kma_initd`.

The binaries `ssh` and `sshd` have been modified to request the KMA to have access to the protected data repository at the time of execution and to let users specify what type of operation must be performed (`makesecure`, `secure` or `makeinsecure`).

The first modification required by each application is introducing a new command line parameter to notify the type of operation requested by the user. For this purpose the files `readconf.c` and `servconf.c` have been updated by adding the new field `kma_mode` in the “`options`” structure and by modifying the routine that parses the command line in the `main()` function.

The output of the diff command applied to the original source code of `ssh` (`ssh.c`) and the source code of the KMA-enabled version:

```
      while ((opt = getopt(ac, av,
-         "1246ab:c:e:fgi:kl:m:no:p:qstvxACD:F:I:L:MNO:PR:S:TVw:XY")) !=
-1) {
+         "1246K:ab:c:e:fgi:kl:m:no:p:qstvxACD:F:I:L:MNO:PR:S:TVw:XY")) !
= -1) {
            switch (opt) {
            case '1':
                  options.protocol = SSH_PROTO_1;
@@ -286,6 +288,14 @@ main(int ac, char **av)
            case '6':
                  options.address_family = AF_INET6;
                  break;
```

```
+           case 'K':
+                 if (strcmp(optarg, "makesecure") == 0)
+                       options.kma_mode = 1;
+                 if (strcmp(optarg, "secure") == 0)
+                       options.kma_mode = 2;
+                 if (strcmp(optarg, "makeinsecure") == 0)
+                       options.kma_mode = 3;
•   break;
```

Then both of applications, in `ssh.c` and `sshd.c`, call the function `kmafs_main()`, exported by a KMA shared library, passing to it the type of operation as argument and wait for KMA to activate the data repository associated; finally the applications read the exit status:

```
+     if(options.kma_mode >0)
+           if((kma_status=kmafs_main(0, options.kma_mode, buf)) != 0)
+                 return kma_status;
```

If the requested operation is `makesecure` or `makeinsecure`, after the completion of the requested operation, the applications end without executing their normal tasks. Otherwise, if the requested operation is `secure` and the exit status of the `kmafs_main()` function is zero (i.e. operation successful), then the applications behave as expected and perform the input/output operations on their files using the KMA protected repository. If the `kmafs_main()` function fails, none of the previous operations is executed and the application just ends.

The `makesecure` and `makeinsecure` operations makes KMA read the list of files that will be copied from the original location to the KMA protected repository (i.e. protected) in the first case and vice versa in the second case (i.e. restored). The list of files to protect is stored in the files `/etc/kma/ssh_kma_list` for `ssh` and `/etc/kma/sshd_kma_list` for `sshd`.

2.1 Content of the file `ssh_kma_list`

```
e     $HOME/.ssh/config          config
e     $HOME/.ssh/id_rsa          id_rsa
e     $HOME/.ssh/id_rsa.pub      id_rsa.pub
e     $HOME/.ssh/id_dsa          id_dsa
e     $HOME/.ssh/known_hosts     known_hosts
```

2.2 Content of the file `sshd_kma_list`

```
e     /etc/ssh/sshd_config              sshd_config
e     /etc/ssh/ssh_host_key             ssh_host_key
e     /etc/ssh/ssh_host_rsa_key         ssh_host_rsa_key
e     /etc/ssh/ssh_host_dsa_key         ssh_host_dsa_key
e     /etc/ssh/ssh_host_key.pub         ssh_host_key.pub
e     /etc/ssh/ssh_host_rsa_key.pub     ssh_host_rsa_key.pub
e     /etc/ssh/ssh_host_dsa_key.pub     ssh_host_dsa_key.pub
```

3 List of Abbreviations

Listing of term definitions and abbreviations used in this document (IT expressions and terms from the application domain).

Abbreviation	Explanation
KMA	Key and data Management Adaptation layer
SSH	Secure SHell

4 Related Work

/1/ OpenSSH
http://www.openssh.org/

/2/ IETF RFC 4251, The Secure Shell (SSH) Protocol Architecture
January, 2006

/3/ OpenTC IST-027635/D03c.4/FINAL 2.00
Key Management Adaptation (KMA) service source code and documentation
Version 2.00
June, 2008

D03c.6 OpenSSL engine/DAA enhancement design specification

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Internal deliverable

Deliverable reference number	IST-027635/D06c.6/FINAL | 1.10
Deliverable title	OpenSSL engine/DAA enhancement design specification
WP contributing to the deliverable	WP03c
Due date	Dec 2007 – M24
Actual submission date	Jun 30, 2008 (revised version)

Responsible Organisation	POL
Authors	Gianluca Ramunno, Davide Vernizzi (editor)
Abstract	This deliverable specifies the design of the enhancements to OpenSSL to support DAA-TLS, a flavor of TLS enhanced with group authentication through the DAA protocol.
Keywords	OPEN_TC, TPM, TLS, OpenSSL, DAA

Dissemination level	Public
Revision	FINAL | 1.10

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

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1 Introduction

This document specifies the design and the interfaces of the enhancements to OpenSSL [3] to implement DAA-TLS, a flavor of the Transport Layer Security (TLS) [5] protocol enhanced with a (anonymous/pseudonymous) group authentication scheme for the client side, based on Direct Anonymous Attestation protocol (DAA) [7] and specified in [4].

In the first part of the document a low level enhancement to OpenSSL is specified to support generic TLS hello extensions as defined in [5] and the TLS supplemental data handshake message defined in [6]; this enhancement is generic and can be used for any other application than the DAA-based authentication.

The second part of the document focuses on a high-level module based on the low level enhancement and on the TCG Software Stack (TSS). This module implements the DAA-based authentication via TLS hello extensions and supplemental data and provides an application with a simple API to ease the setup the DAA-based authentication on the client side. Using this module, any existing application built upon OpenSSL can easily modified (only a slight update is required) to use the new authentication scheme with TLS.

2 Overview of the enhancements to OpenSSL

OpenSSL can be used to implement the DAA-based authentication. OpenSSL offers various advantages; the most interesting are that it fully implements the TLS protocol, it is released under an open source license and it offers the possibility to separate the execution of the protocol from the cryptographic functions using the engine interface.

In order to use OpenSSL for DAA-TLS, it is necessary to add the support to the features used in the design of the protocol. The stable version of OpenSSL (0.9.8x) does not provide any of these features, while the development version (0.9.9x) only has a limited support for the extensions to TLS handshake hello messages. No support is natively provided for supplemental data message. Both these extensions of the TLS protocol were used in the design of DAA enhancement for TLS; therefore, such support must be added to OpenSSL.

In detail, the major modifications have to be done to **`libssl`**, the OpenSSL module implementing the TLS protocol. In this library we added a generalized support to the extensions of the hello messages and a new message of the handshake to transport the supplemental data.

3 Low level enhancement for generic applications

3.1 Hello extensions

A hello message may transport many different hello extensions that are handled by the receiver [5]. An extension is defined by a type (identifier) and a payload. OpenSSL version 0.9.9.x provides only a partial support to few extensions specified in [5]. This document defines the design of an enhancement to OpenSSL, based on internal lists, to manage the extensions. Each extension is added to a list that is parsed by OpenSSL when the hello message is prepared. OpenSSL adds the extensions present in the list to the client hello. When this message is transmitted, the receiver parses the list of the received extensions.

The received extensions are handled using callback functions. Each extension must be associated with its own callback function, but each function can be associated with many different extensions.

The complete workflow for the management of an extension is shown in Figure 1, Figure 2 and Figure 3. Figure 1 shows the steps needed to set up the extension while

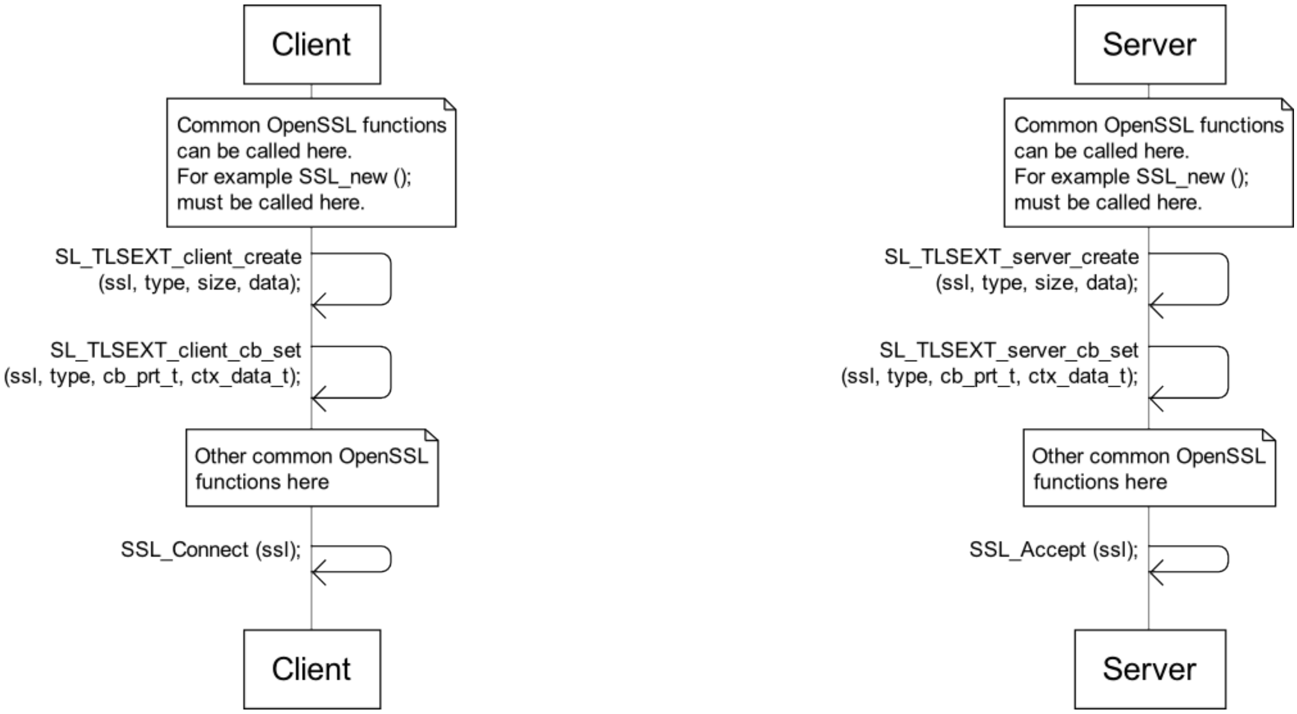

Figure 1: operations to set up the usage of hello extensions in OpenSSL

Figure 2 and Figure 3 show the transmission and the handling of the received extensions on both client and server sides.

In order to create an extension, a SSL object must be instantiated. This is a standard object provided by OpenSSL libraries to manage a SSL/TLS connection and can be created using specific functions; the creation of the SSL object is out of the scope of this specification, but further information can be found in [3].

On the client side, once the SSL object is created, it is possible to add to it the TLS extensions to send, by calling the function

```
TLSEXT_GENERIC * SSL_TLSEXT_client_create (SSL *ssl,            // in
                                           int type,            // in
                                           int size,            // in
                                           unsigned char *data  // in
                                          );
```

where **ssl** it the pointer to the SSL object, **type** is the type of the extension corresponding to the field **extension_type** defined in [5] (whose value is defined by each extension specification) and **data** is a buffer, **size** bytes long, containing the extension's payload to be transmitted. The encoding of the payload depends on the extension specification; therefore it must the managed by the calling application.

If the extension is successfully added to the internal list, the function returns a pointer to **TLSEXT_GENERIC**, an internal object that contains the extension type **tlsext_type**, the payload **tlsext_data** long **tlsext_data_length** bytes and **ctx_data_t** a pointer to the data context. If the extension cannot be added, the function returns NULL. This function must be called before the time when OpenSSL has to send the client hello extension; since the latter is carried over the first message exchanged between client and server, **SSL_TLSEXT_client_create ()** must be called before the handshake begins.

TLSEXT_GENERIC is defined as:

```
typedef struct tlsext_generic_st {
     int tlsext_type;                /* Type of the extension */
     int tlsext_data_length;         /* Length of the payload */
     unsigned char * tlsext_data;    /* Buffer containing the
                                      * payload's extension   */
     void *ssl_tlsext_ctx_data;      /* Context: application
                                      * defined data structure
                                      * passed to callback
                                      * functions             */
} TLSEXT_GENERIC;
```

Each extension to be received is handled by a callback function. Therefore it is necessary to register such callback function in advance (i.e. before the handshake begins) for the extension the server will send, by calling the function:

```
int SSL_TLSEXT_client_cb_set (SSL *ssl,             // in
                              int type,             // in
                              void *cb_prt_t,       // in
                              void *ctx_data_t      // in
                             );
```

where **ssl** it the pointer to SSL object, **type** is the type of the extension, **cb_prt_t** is a pointer to the callback function to register and **ctx_data_t** is a pointer to the data context, a structure that contains any data that might be useful for the callback function to correctly handle the data: it can be used by the calling application to pass preset data to the callback functions and/or by the callback function to return data to the calling application. Therefore this structure must be defined within the calling application, and its type cast to **(void *)** when passed to the aforementioned function to set up the callback function. The latter must then cast back the structure to its original data type before accessing it through the member **ssl_tlsext_ctx_data** of **TLSEXT_GENERIC** structure.

The callback function must have the following prototype:

```
void cb_func (SSL *, TLSEXT_GENERIC *);
```

There operations (creating an extension and registering a callback function) must be performed for each extension which the application on the client side has to respectively send and receive. Then the application can implement the standard OpenSSL workflow: when the client calls the function **SSL_connect()**, the network connection is created and the handshake begins: the extensions will be automatically handled by OpenSSL.

Server side versions of these functions also exist

```
TLSEXT_GENERIC * SSL_TLSEXT_server_create (SSL *ssl,            // in
                                           int type,            // in
                                           int size,            // in
                                           unsigned char *data  // in
                                          );

int SSL_TLSEXT_server_cb_set (SSL *ssl,              // in
                              int type,              // in
                              void *cb_prt_t,        // in
                              void *ctx_data_t       // in
                             );
```

respectively. The server must call the function **SSL_accept()** to prepare itself for the handshake.

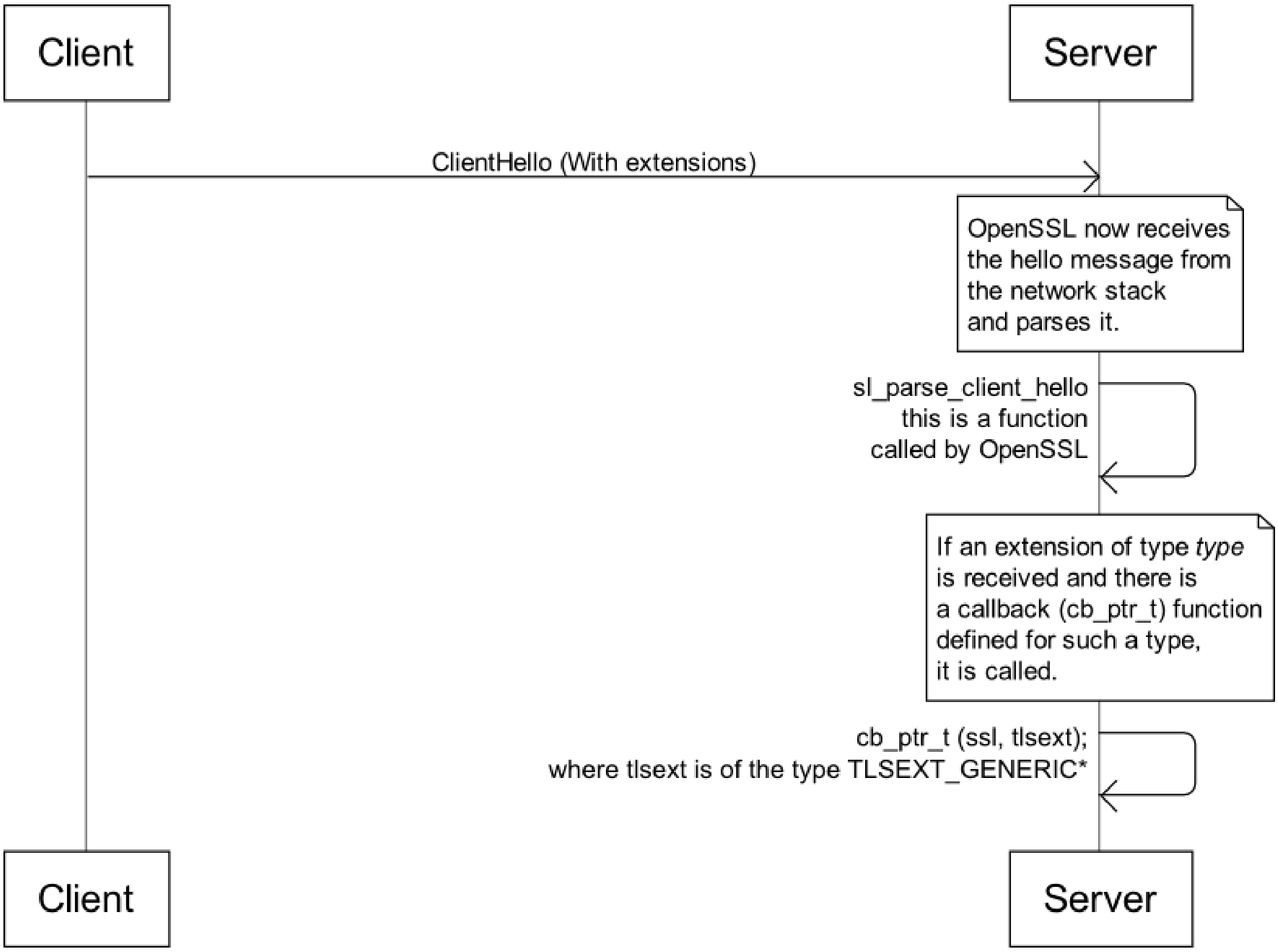

Figure 2: Client hello extension sent to (and parsed by) server

The first message of the TLS handshake is the client hello message, sent by the client to the server (see Figure 2). The client creates the message including all extensions previously defined using

```
SSL_TLSEXT_client_create (ssl, type, size, data);
```

An example on how to set up the extension is given in Annex B.1.1.1. When the message is ready, it is sent over the network to the server. The latter parses the message and for any TLS extension found, it verifies if the related callback function was previously registered; if the case, this function is called.

When executed, the callback function can access the payload of the received extension as well as the context data via **ssl_tlsext_ctx_data**, member of the **TLSEXT_GENERIC** and set to the pointer **ctx_data_t** passed when registering the callback function.

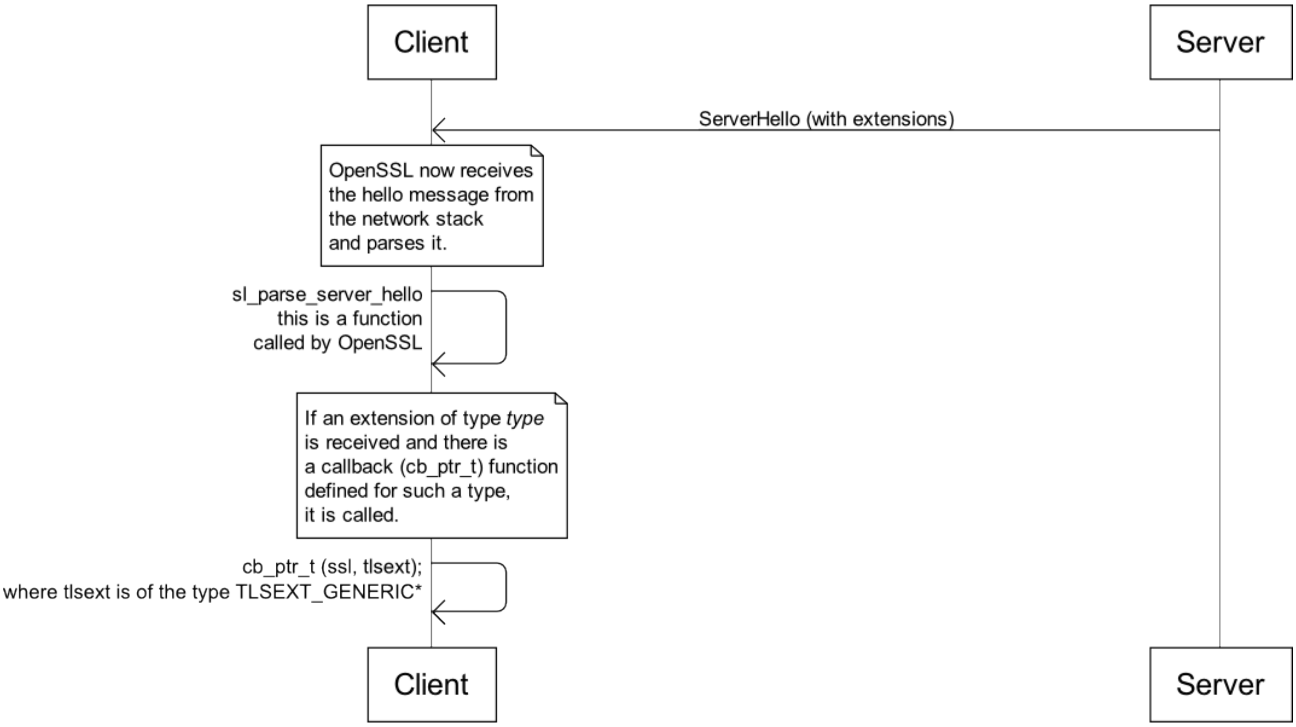

Figure 3: Server hello extension sent to (and parsed by) client

When the server has processed the client hello, it creates the server hello message including the extensions and sends it to the the client (see Figure 3). The handling of the server hello on the client is similar to the handling of the client hello on the server described before. However, the client requires some additional checks: [5] imposes that the extensions sent by server must be a subset of the extensions sent by the client; if the server sends an extension of a type that was not sent by the client in its client hello, the client should terminate the TLS handshake. In order to do this, the client verifies that the extensions sent by the server are a subset of the extensions previously sent by itself. This behavior is natively enforced by OpenSSL.

If the server application creates any extension before the handshake begins and afterwards the client does not send the such extension in the client hello message, then the server behavior – sending an extension of a type that was not requested by the client – is not compliant with the specification, causing the termination of the handshake by the client. This wrong behavior can be avoided in the server application by creating any extension for the server hello message only for the extensions included in the received client hello message. In order to do this, any call to the function:

```
SSL_TLSEXT_server_create (ssl, type, size, data);
```

must be moved inside the callback function on the server application handling the received client extension of the same **type**.

3.2 Supplemental data message

Supplemental data are defined in [6]. A supplemental data is an additional message sent by the server and/or the client. The specification imposes each party can send at most one single supplemental data message, each one carrying one or more **supplemental data entries**. Each one must be defined through a specification. Hence if an application wants to send many different supplemental data entries, these must be packed into one single message.

All functions defined in the following may be use by both client and server applications.

The supplemental data message will be created by a callback function called OpenSSL during the handshake, just before being sent (according to [6]); this way the callback function can retrieve data carried by a hello extension just received. It is possible to register such callback function as:

```
int SSL_SUPPL_DATA_prepare_set (SSL *ssl,            // in
                                 void *my_prepare,    // in
                                 void *ctx_data       // in
                                );
```

where **ssl** is the pointer to the SSL object, **my_prepare** is the pointer to the callback function that will create the supplemental data message and **ctx_data** is a pointer to a structure that contains any context data that the callback function may need to create the message; it can be used by the calling application to pass preset data to the callback functions and/or by the callback function to return data to the calling application. Therefore this structure must be defined within the calling application, and its type cast to **(void *)** when passed to the aforementioned function to set up the callback function. The latter must then cast back the structure to its original data type before accessing it. The structure pointed by **ctx_data** can be the same passed to the callback function handling the received hello extension. This way it is possible to pass data carried over the extension to the callback function handling the supplemental data message to be sent.

OpenSSL will call the callback function during the handshake, when it needs to prepare the supplemental data message, namely just before sending it over the network.

According to [6] at least one supplemental entry must be carried by the message. Each supplemental data entry to deliver must be prepared within the callback function **my_prepare** by calling the function

```
int SSL_SUPPL_DATA_push (SSL *ssl,                   // in
                          int type,                   // in
                          int size,                   // in
                          unsigned char *data         // in
                         );
```

where **ssl** is the pointer to the SSL object, **type** is the type of the supplemental data entry corresponding to **supp_data_type** defined in [6] (whose value is defined by each supplemental data entry specification), and **data** is a buffer, **size** bytes long, containing the supplemental data entry's payload to be transmitted. The encoding of the payload depends on the supplemental data entry specification; therefore it must the managed by the calling application. This function will add **data** to an internal list that will be parsed by OpenSSL when the message is prepared.

Once the message is ready, it is sent over the network; the message is then handled by OpenSSL via callback functions called when the message is received. Each callback function handles a supplemental data entry of one single specific type; a callback function can be registered using the function:

```
SSL_SUPPL_DATA_cb_set (SSL *ssl,                    // in
                        int type,                   // in
                        void *cb_handle             // in
                        void *ctx_data              // in
                       );
```

where **ssl** is the pointer to SSL object, **type** is the type of the supplemental data entry, **cb_handle** is the pointer to the callback function used to handle a supplemental data entry of type **t** and **ctx_data** is a pointer to a structure that contains any context data that the callback function may need. The callback function must have the following prototype:

```
void cb_handle (SSL *ssl, int type,
       unsigned char *data, int size, void * ctx_data);
```

where **ssl** is the pointer to the SSL object, **type** is the type of the supplemental data entry to handle, **data** is a buffer of size **size** that contains the payload of the supplemental data entry and **ctx_data** is a pointer to a structure that contains any context data that the callback function may need.

It is also possible to define a callback function for debug purposes. Such function will be called by OpenSSL after the supplemental data message creation is complete, just before sending it. This function allows developers to check whether the creation of the supplemental data was successful. The debug callback function can be defined as:

```
ssl->suppl_data->debug_cb = &(suppl_data_debug);
```

where **ssl** is the SSL object, and **suppl_data_debug_cb** is the debug function. Such function must have the following prototype:

```
void suppl_data_cb_srvr (SSL *ssl, unsigned char *data, int size);
```

where **ssl** is the pointer to the SSL object and **data** is a buffer of size **size**.

The complete workflow for the supplemental data is shown in Figure 4 and Figure 5. Figure 4 shows the steps needed to setup the supplemental data, and Figure 5 shows the handshake between client and server.

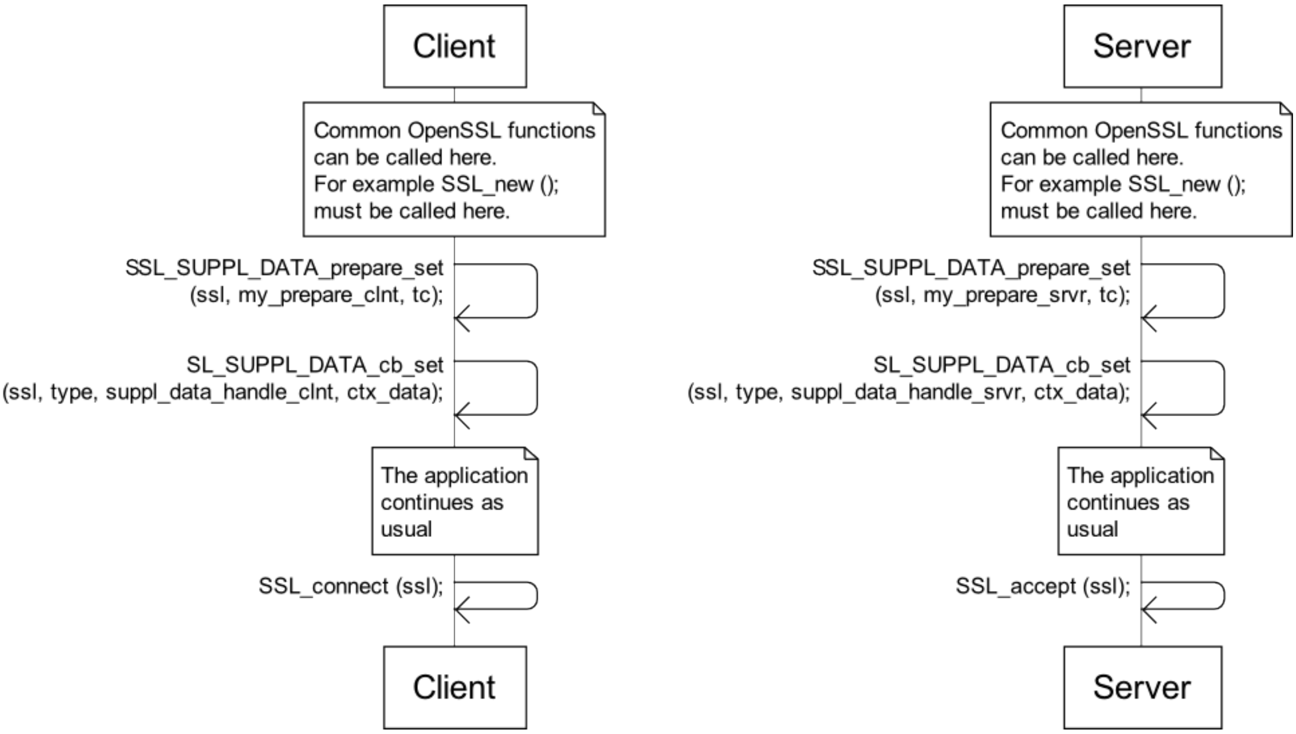

Figure 4: Steps to setup the supplemental data.

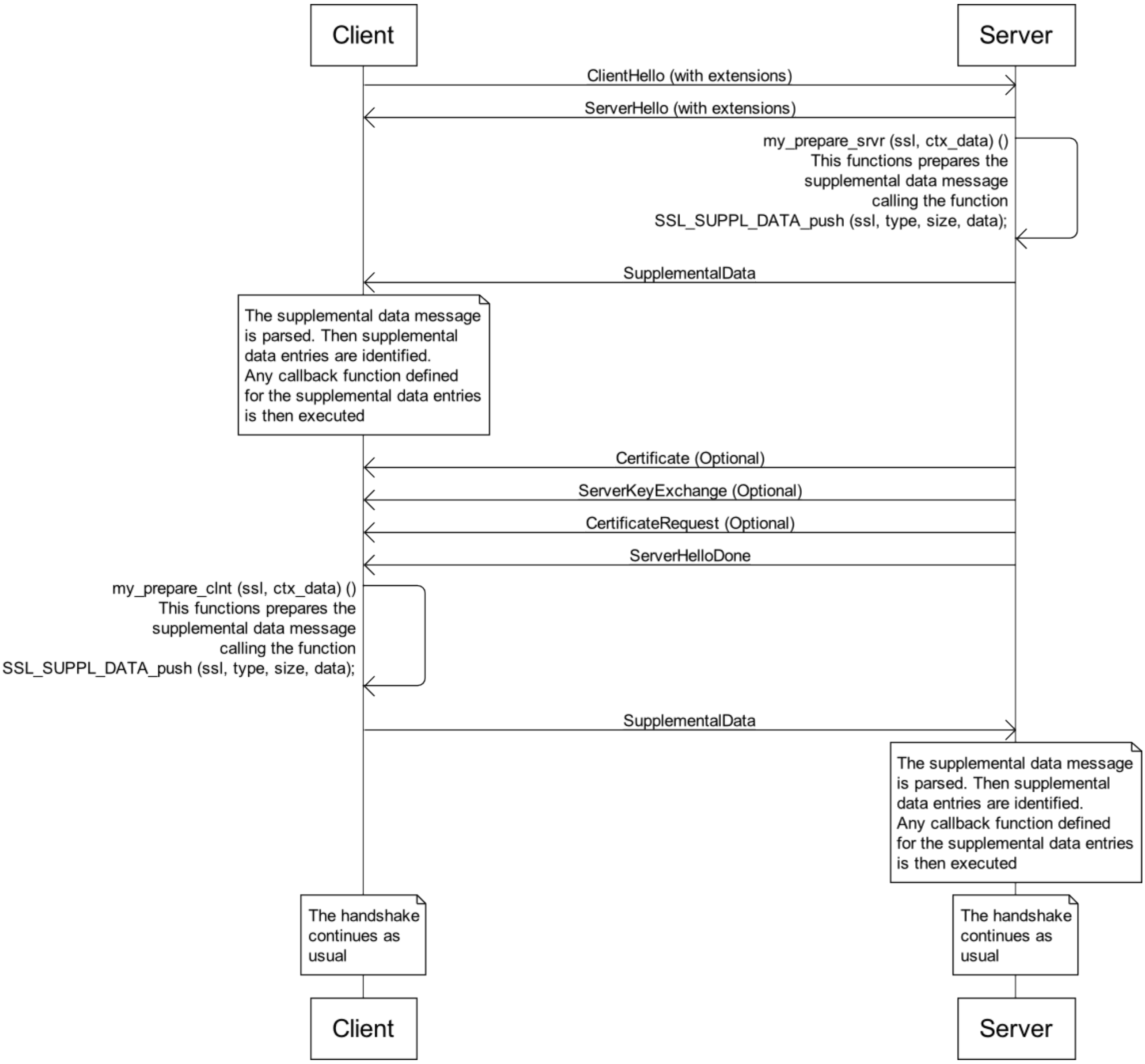

Figure 5: Handshake between client and server using the supplemental data.

3.3 Supplemental data negotiation using the extensions

The supplemental data specification imposes that each supplemental data entry MUST be negotiated using the hello extensions. Furthermore, the hello extension specification imposes that the server must not send any extension that was not explicitly requested by the client. In the following it is explained how to achieve such negotiation. Note that in the example the supplemental data message is sent by both the client and the server. In real scenarios, it is also possible that one of the peers does not send any supplemental data message; the actual behavior depends on the type of the supplemental data message. Furthermore, according to [6], if a supplemental data message is present, it MUST be non empty, meaning that at least one supplemental data entry MUST be transported within. The negotiation happens as follow.

1. The client creates the hello extension for requesting the supplemental data entry and sends the extended client hello message. This extension means that the client is proposing to the server to use a particular feature that requires the exchange of a supplemental data entry.
2. If the server receives the hello extension, it creates the corresponding extended server hello. This can be done by moving the creation of the extension within the callback function that handle the corresponding extension sent by the client as specified in section 3.1.
   Furthermore the server creates the supplemental data entry corresponding to the extension received from the client and sets the appropriate callback function to handle the supplemental data that the client will send.
3. The client receives the extended server hello message. The presence of the extension means that the server agreed to use that feature and, thus, an appropriate supplemental data entry must be created; such creation happens while the client is handling the server extension. Moreover, the client sets the appropriate callback function to handle the supplemental data that the server will send.
4. The handshake continues as described previously.

A sketch of the negotiation is shown in Figure 6.

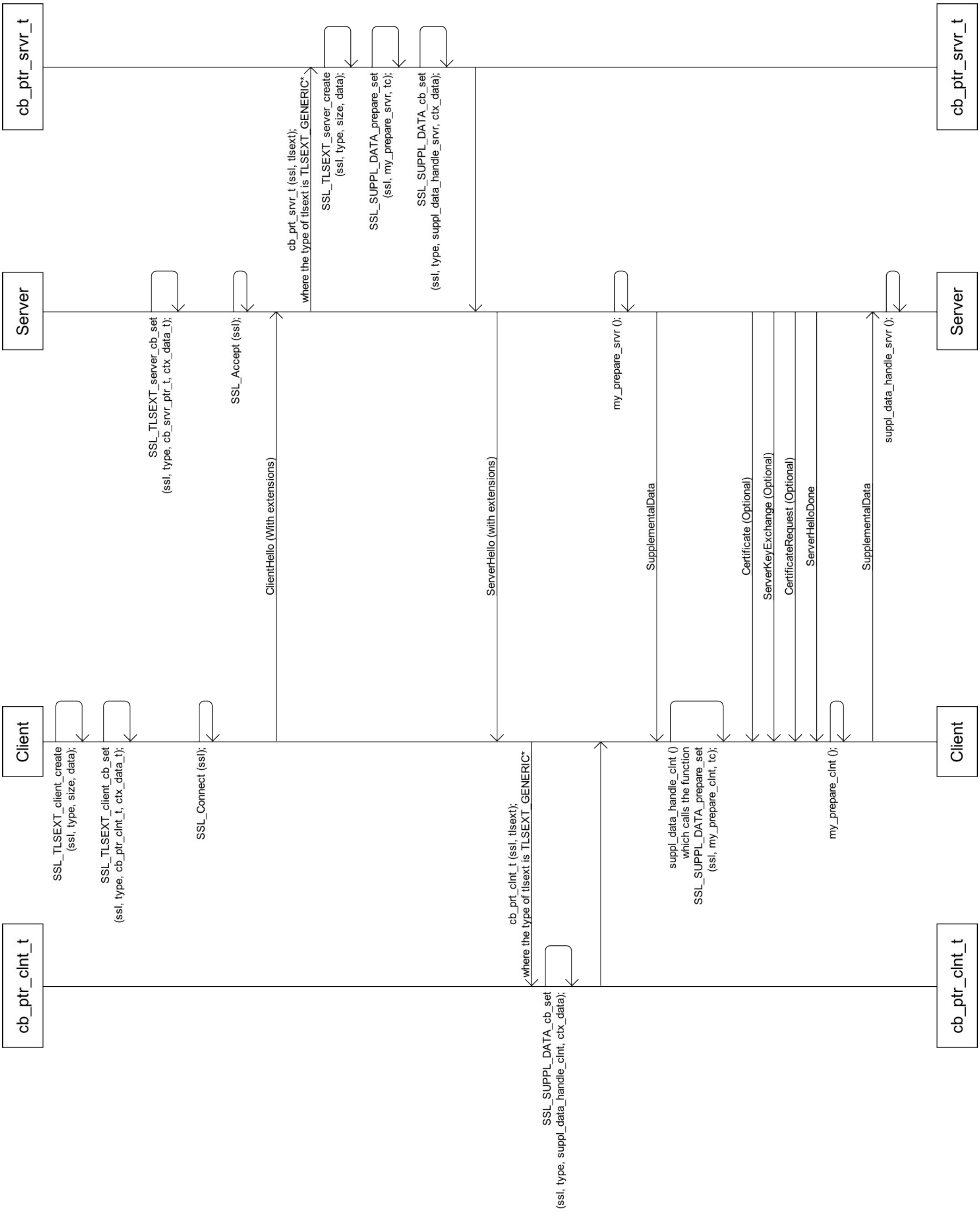

Figure 6: Supplemental data negotiation using the extensions

4 DAA authentication library API

In order to ease the work of the developers, it is possible to simplify the creation of a TLS channels that implements the anonymous authentication through the DAA protocol by using the **DAA authentication library** (**DaaAuthLib**). This library takes care of creating the hello extensions and supplemental data necessary to use the DAA for anonymous or pseudonymous authentication. Note that the DAA protocol requires interaction with the Trusted Software Stack (TSS) for running the DAA-specific functions.

The library is built around the data structure **Daa_Auth**; this object[1] contains all the information needed for the DAA for anonymous authentication. **DaaAuthLib** provides constructors and destructors for its objects as well as getters and setters for the members of the objects.

A **Daa_Auth** can be created using the constructor:

```
Daa_Auth *daa;
daa = DAuth_new (peer);
```

where **peer** can assume the values **PLATFORM** or **VERIFIER** and indicates to the constructor whether the function is used by the TC-enabled platform or by the verifier. This is necessary because the behavior of the platform and of the verifier is different and this flag allows the library to behave correctly.

The structure can be deallocated using the destructor:

```
DAuth_del (daa);
```

Daa_Auth contains all the data necessary for the DAA anonymous authentication: both the data that must be transmitted to the counterpart and the local data (e.g. handlers to TSS objects) that must be used locally to sign or verify the signature.

The **Daa_Auth** structure is defined as:

```
typedef struct Daa_Auth_st {
   Basename                 wanted_basename;
   Basename                 basename;
   Nonce                    nonce;
   SignedAdditionalData     signed_additional_data;
   SignedHash               signed_hash;

   TSS_HTPM*                hTPM;
   TSS_HDAA_CREDENTIAL*     hDAACredential;
   TSS_HDAA_ISSUER_KEY*     hIssuerKey;
   TSS_HDAA_ARA_KEY*        hARAKey;
   TSS_HHASH*               hARACondition;

   TSS_DAA_SIGNATURE*       signature;
```

1 **DaaAuthLib** is written in C, a non-object-oriented programming language, but its logical organization reminds the object--oriented paradigm, hence the main data structures will be referred as **objects**.

```
    uint8_t                      is_auth_valid;
} Daa_Auth;

typedef struct Basename_st {
    uint8 basename_length;
    unsigned char * basename;
} Basename;

typedef struct Nonce_st {
    uint8 nonce_length;
    unsigned char * nonce;
} Nonce;

typedef struct SignedAdditionalData_st {
    uint16 data_length;
    unsigned char * data;
} SignedAdditionalData;

typedef SignedHash_st {
    uint8 hash_length;
    unsigned char * hash;
} SignedHash;
```

where:

- **wanted_basename** is the basename wanted by the verifier. If the verifier wants to use the pseudonymity, it must place the information needed to compute the fixed basename here. If it wants to use the anonymity, then this field must be NULL.
- **basename** is the actual basename used in the DAA signature. This field is automatically filled on the verifier by the library using the **Tspi_DAA_Verifier_Init ()** function provided by the TSS.
- **nonce** is the nonce generated by the **Tspi_DAA_Verifier_Init ()** function; this nonce is computed by the verifier and the it's transmitted to the TC-platform.
- **signed_additional_data** if present contains the additional data that compose the DAA signature together with the client certificate. For the TC-platform, this represents the data that must be signed, while for the verifier this represents the data that was signed by the platform. The verifier uses this field, if present, to verify the DAA signature.
- **signed_hash** is the hash that was actually signed by the TC-platform. This filed is set by the platform and is used by the verifier to verity the DAA signature. Note that this field and the previous one must be used at the end of the handshake to verify the authentication. In details the verifier must concatenate the certificate used for the TLS authentication of the TC-platform and the **signed_additional_data** and then it must compute a hash of the concatenated data; if this latter hash corresponds to the signed hash, then the DAA

anonymous authentication is verified.

- **`hTPM`** is the handler to the TPM object. This field contains the handler as it was created by the TSS. This object is used by the TC-platform when it makes the DAA signature.
- **`hDAACredential`** is the handler to the object that contains the DAA credentials.
- **`hIssuerKey`** is the handler to the object that contains the information about the issuer needed by the verifier to verify the DAA signature. This information is used by the verifier.
- **`hARAKey`** is the handler to the revocation authority object. At the moment it is not used and should be set to NULL.
- **`hARACondition`** is the handler to the object that describes the condition under which the revocation authority should reveal the identity of the platform. At the moment it is not used and should be set to NULL.
- **`signature`** contains the information related with the DAA signature. The signature is computed on the TC-platform and then is sent to the verifier.
- **`is_auth_valid`** is an integer value that is used on the verifier to specify if the authentication was verified or not. This field can assume the following values:

```
enum {
   Rogue (0), Unknown (1), DAA_signature_ok (2),
   Authenticated (3)
}
```

  where **`Rogue`** means that the verifier was not able to authenticate the platform; this could happen if the DAA signature is incorrect or if the verifier was not able to verify the hash that was signed by the platform; **`Unknown`** is the default value that is used at the beginning of the TLS handshake; **`DAA_signature_ok`** means that the verifier was able to verify the DAA signature, but the hash that was signed is not yet verified; **`Authenticated`** is the last value that the field assume in the case the authentication was successful. This field is updated by the library and it should only be read by the verifier at the end of the handshake: reading this field before the handshake is completed returns an non-meaningful value.

The library provides a set of functions that can be used to correctly write into and retrieve data from the **`Daa_Auth`** structure. The functions allocates the necessary data memory; this memory must be deallocated when non needed anymore.

These functions can be used by the TC-platform, by the verifier or by both the entities.

4.1 Platform-only functions

- A function to read the basename:

```
int DAuth_Bname_get (Daa_Auth* daa,        // in
                     char** bname,         // out
                     uint8* len            // out
                    );
```

where **daa** is a pointer to the **Daa_Auth** structure and **bname** and **len** represent a buffer that will contain the basename and its length respectively. The function fills the buffer and the length variables and returns 1 if the operation is successful, and 0 otherwise.

- A function to read the nonce:

```
int DAuth_Nonce_get (Daa_Auth* daa,              // in
                     unsigned char** nonce,      // out
                     uint8* len                  // out
                    );
```

where **daa** is a pointer to the **Daa_Auth** structure and **nonce** and **len** represent a buffer that will contain the nonce and its length respectively. A fresh nonce is automatically created by the library when the relative hello extension is sent to the TC-platform. The function fills the buffer and the length variables and returns 1 if the operation is successful, and 0 otherwise. This function is not necessary because the Nonce is automatically used by the library and not meaningful for the applications, but it is provided in case the application wants to use the nonce for any other purpose.

- A function to set the hash to sign:

```
int DAuth_SignedHash_set (Daa_Auth* daa,         // in
                          unsigned char* data    // in
                          uint8 len              // in
                         );
```

where **daa** is a pointer to the **Daa_Auth** structure and **data** and **len** represent a buffer that contains the data to sign and its length respectively. This function is only called by the TC-platform before the handshake begins and sets in the s**igned_hash** field in the **Daa_Auth** structure. These data will be copied by the library in the Verifier's structure during the handshake. The verifier can use the data after the handshake finishes. The function returns 1 if the operation is successful, and 0 otherwise.

- A function to set the additional data to sign:

```
int DAuth_SignedData_set (Daa_Auth* daa,         // in
                          unsigned char* data,   // in
                          uint8 len              // in
                         );
```

- where **daa** is a pointer to the **Daa_Auth** structure and **data** and **len** represent a buffer that contains the data to sign and its length respectively. This function is only called by the TC-platform before the handshake begins and sets in the **signed_additional_data** field in the **Daa_Auth** structure. The platform should call this function only if it wants to sign additional data more than the certificate used for the client authentication. These data will be copied by the library in the Verifier's structure during the handshake. The verifier can use the data after the handshake finishes. The function returns 1 if the operation is successful, and 0 otherwise.

4.2 Verifier-only functions

- A function to set the basename:

```
int DAuth_Bname_set (Daa_Auth* daa,              // in
                     unsigned char* bname,       // in
                     uint8 len                   // in
                    );
```

where **daa** is a pointer to the **Daa_Auth** structure and **bname** and **len** represent a buffer that contains the basename and its length respectively. This function should be used only by the Verifier before the DAA authentication starts. If the peers agreed to use pseudonymity, **bname** must be **NULL** and len must be 0; in this case, the TC-platform will generate a fresh random basename for each anonymous authentication and will return such basename to the Verifier; finally, at the end of the TLS handshake, the library will copy the random basename in the structure. The function returns 1 if the operation is successful, and 0 otherwise.

- A function to read the additional data signed:

```
int DAuth_SignedData_get (Daa_Auth* daa,         // in
                          unsigned char** data, // out
                          uint8* len            // out
                         );
```

where **daa** is a pointer to the **Daa_Auth** structure and **data** and **len** represent a buffer that will contain the additional data signed and its length respectively. This function is only called by the Verifier after the handshake finishes. The function fills the buffer and the length variables and returns 1 if the operation is successful, and 0 otherwise.

- A function to read the hash signed:

```
int DAuth_SignedHash_get (Daa_Auth* daa,         // in
                          unsigned char** data, // out
                          uint8* len            // out
                         );
```

where **daa** is a pointer to the **Daa_Auth** structure and **data** and **len** represent a buffer that will contain the signed hash and its length respectively. This function is only called by the Verifier after the handshake finishes. The function fills the buffer and the length variables and returns 1 if the operation is successful, and 0 otherwise.

- A function to read the DAA signature made by the TC-platform:

```
int DAuth_Signature_get (Daa_Auth* daa,          // in
                         unsigned char** data,  // out
                         uint8* len             // out
                        );
```

where **daa** is a pointer to the **Daa_Auth** structure and **data** and **len** represent a buffer that will contain the signature and its length respectively. This function is only called by the Verifier after the handshake finishes. The function fills the buffer and the length variables and returns 1 if the operation is successful, and 0 otherwise.

- A function to verify the authentication:

```
int DAuth_verify_authentication (Daa_Auth* daa        // in
                                  X509 * x509cert     // in
                                 );
```

where **daa** is a pointer to the **Daa_Auth** structure used in the handshake and **x509cert** is a pointer to the certificate used by the TC-platform during the authentication. This function concatenates the TLS certificate and the additional signed data, computes the hash of this concatenated data, compares it to the hash signed by the platform and eventually updates the field is_auth_OK of the Daa structure and returns 1 if it was successful or 0 if any error happened.

- A function to check the state of the authentication:

```
int DAuth_authentication_state (Daa_Auth* daa   // in
                               );
```

where **daa** is a pointer to the **Daa_Auth** structure used in the handshake. This function returns the current status of the authentication verification process. In particular, if used after the handshake is finished, it tells if the verifier authenticated the platform or not.

- A function to store a DAA signature:

```
int DAuth_Signature_store (Daa_Auth* daa        // in
                          );
```

where **daa** is a pointer to the **Daa_Auth** structure used in the handshake. This function is used when pseudonymity is in place to keep track of successive signatures made by the same platform; this function saves in the internal store of the library the DAA signature. This function is only called by the Verifier after the handshake finishes. The function returns 1 if the operation is successful, and 0 otherwise.

- A function to store a DAA signature:

```
int DAuth_Signature_count (Daa_Auth* daa        // in
                          );
```

where **daa** is a pointer to the **Daa_Auth** structure used in the handshake This function is used when pseudonymity is in place to keep track of successive signatures made by the same platform; this function look in the internal store of the library for the other DAA signature made by the same platform. This function is only called by the Verifier after the handshake finishes. The function returns the number of the DAA signature found, 0 if no previous signature were found and -1 if the operation was not successful.

4.3 Functions used by both the platform and the verifier

Once the **Daa_Auth** object has been created, it contains all the information needed to start an anonymous authentication made usign the DAA and the TLS protocol. In order to setup all the hello extensions and supplemental data needed it is necessary to call the function:

```
DAuth_DAA_anonym_auth_new (SSL* ssl,          // in
                           Daa_Auth* daa      // in
                          );
```

where **ssl** is the SSL object created and used by OpenSSL and **daa** is a pointer to the **Daa_Auth** structure that contains all the information needed. Note that the this function must be called after the **ssl** object was created using:

```
ssl = SSL_new(...);
```

After this function is called, the application does not need to call the **DaaAuthLib** library again and the TLS channel can be created with the OpenSSL function

```
SSL_connect(ssl);
```

where **ssl** is the same object of type **SSL** used in the creation of the **Daa_Auth** object.

A the end of the handshake, the library will fill the missing fields of **daa** so that the anonymous authentication can be completed.

4.4 Execution flow example

Client	Server
Setup ● The application creates the TSS context objects (**hDAACredential**, **hTPM**, **signData**, **hARAKey***, **hARACondition***) ● The application creates the DAA context using the function **DAuth_new ()** and sets the additional sign data and the hash to sign with the functions **Dauth_SignedData_set** and **Dauth_SignedHash_set** ● The TSS objects are connected with the DAA context ● **Dauth_DAA_anonym_auth_new()** is called to setup the anonymous authentication ● The application creates the OpenSSL context ● The application calls the OpenSSL function **SSL_connect()** to setup the channel	**Setup** ● The application creates the TSS context objects (**hDAACredential**, **hTPM**, **signData**, **hARAKey***, **hARACondition***) ● The application creates the DAA context ● Wanted basename is set up in the DAA context ● **Dauth_DAA_anonym_auth_new()** is called to setup the anonymous authentication ● The application creates the OpenSSL context ● The application calls the OpenSSL function **SSL_accept()** to setup the channel
Hello extension	

<table>
<tr><td>The extension was created in the setup phase by the Dauth_DAA_anonym_auth_new() function.
In this step it is send automatically by OpenSSL</td><td></td></tr>
<tr><td></td><td>Preparing the hello extension
If the server receives the hello extension from the client, then the callback function prepared in the setup phase is called; this function will:
call the TSS function Tspi_DAA_Verifier_Init() which return the basename and the nonce
create an extension to send back to the client within the server hello
register a callback function for the supplemental data</td></tr>
<tr><td>Handling hello extension from the server
if the client receives the extension in response from the server, then the callback is called; this function will:
retrieve nonce and basename from the extension
retrieve the hash to sign from the DAA context
call the TSS function Tspi_TPM_DAA_Sign
prepare the supplemental data to send back</td><td></td></tr>
<tr><td colspan="2">Handshake continues as usual ...</td></tr>
<tr><td></td><td>Receiving the supplemental data from the client
if the supplemental data message is received, then the appropriate callback function is called; this function will:
verify the DAA signature; in order to to this, it must retrieve the signature and the hash signed from the supplemental data and the other parameters (nonce, basename, handlers, ...) from the DAA context</td></tr>
</table>

	◦ Update the field **`is_auth_valid`** in the DAA context
Handshake continues as usual ...	
	`Final check` • the server application retrieves the certificate used by the client for the authentication, concatenates the additional signed data, if present, then ◦ computes a hash of this composed data ◦ verify if it is equal to the one signed by the client. ◦ If this is the case, then client was successfully authenticates. • The computation is done using the function **`Dauth_verify_authentication()`**, while the final check is done with the function **`Dauth_authentication_state()`**.

5 List of abbreviations

Listing of term definitions and abbreviations used in this document (IT expressions and terms from the application domain).

Abbreviation	Explanation
TCG	Trusted Computing Group
DAA	Direct Anonymous Attestation
TLS	Transport Layer Security

6 Referenced Documents

/1/ TCG Specification, Architecture Overview
http://www.trustedcomputing.org
April 28, 2004,
Version 1.2

/2/ TCG Software Stack (TSS) Specification
January 6, 2006,
Version 1.2

/3/ OpenSSL Toolkit www.openssl.org/

/4/ OpenTC D03c.3: SSL/TLS DAA-enhancement specification

/5/ RFC4366 Transport Layer Security (TLS) Extensions
April 2006

/6/ RFC4680 TLS Handshake Message for Supplemental Data
September 2006

/7/ Direct Anonymous Attestation
Ernie Brickell, Jan Camenisch, Liqun Chen
CCS '04: 11th ACM conference on Computer and Communications Security
2004

Annex A (normative): API header files

A.1 Low level enhancement

```
/* Functions used by the applications */
int SSL_SUPPL_DATA_prepare_set (SSL *ssl, void *callback_func, void
*context_data);
int SSL_SUPPL_DATA_cb_set (SSL *ssl, int type, void *callback_func,
void *context_data);
int SSL_SUPPL_DATA_push (SSL *ssl, int type, int size, unsigned char
*data);

/* Structures */
typedef struct tlsext_generic_list_st TLSEXT_GENERIC_STACK;
typedef struct tlsext_generic_st TLSEXT_GENERIC;

struct tlsext_generic_st {
	int tlsext_type;                /* Type of the extension */
	int tlsext_data_length;         /* Length of the extension */
	unsigned char * tlsext_data;    /* Buffer containing data
	                                 * of the extension        */
	void *ssl_tlsext_ctx_data;      /* Context: application
	                                 * defined data structure
	                                 * passed to callback
	                                 * functions */
};


/* Functions used by the applications */

/* The two functions for creating the extension, return the extension
 * they created. This is not really necessary, but may be handy when
 * the application needs to do something with those data.
 */
TLSEXT_GENERIC * SSL_TLSEXT_client_create (SSL *ssl, int type, int
size, unsigned char *data);
TLSEXT_GENERIC * SSL_TLSEXT_server_create (SSL *ssl, int type, int
size, unsigned char *data);
int SSL_TLSEXT_client_cb_set (SSL *ssl, int type, void *callback_func,
void *context_data);
int SSL_TLSEXT_server_cb_set (SSL *ssl, int type, void *callback_func,
void *context_data);

struct ssl_st {

	/* OpenSSL standard ssl_st struct definition here */

	/* Support to generic extensions */
	TLSEXT_GENERIC_STACK *tlsext_generic;

	/* Supplemental data */
```

```
    struct suppl_data_st *suppl_data;
}
```

A.2 DAA Authentication library

```
#include <trousers/tss.h>
#include <stdint.h>
#include <openssl/ssl.h>
#include <openssl/x509v3.h>

/* Data structures */

enum Auth_state_enum {
   Rogue = 0,
   Unknown = 1,
   DAA_signature_ok = 2,
   Authenticated = 3
} Auth_state;

typedef struct Basename_st {
   unsigned char * basename;
   uint8_t basename_length;
} Basename;

typedef struct Nonce_st {
   uint8_t nonce_length;
   unsigned char * nonce;
} Nonce;

typedef struct SignedAdditionalData_st {
   uint16_t data_length;
   unsigned char * data;
} SignedAdditionalData;

typedef struct SignedHash_st {
   uint8_t hash_length;
   unsigned char * hash;
} SignedHash;

typedef struct Daa_Auth_st {
   Basename                     wanted_basename;
   Basename                     basename;
   Nonce                        nonce;

   SignedAdditionalData         signed_additional_data;
   SignedHash                   signed_hash;

   TSS_HTPM*                    hTPM;
   TSS_HDAA_CREDENTIAL*         hDAACredential;
   TSS_HDAA_ISSUER_KEY*         hIssuerKey;
   TSS_HDAA_ARA_KEY*            hARAKey;
   TSS_HHASH*                   hARACondition;
```

```
   TSS_DAA_SIGNATURE*           signature;

   uint8_t                      is_auth_valid;
} Daa_Auth;

/* Function prototypes */

int DAuth_Bname_get (Daa_Auth*,                 // in
                     unsigned char**,           // out
                     uint8_t*                   // out
                      );


int DAuth_Nonce_get (Daa_Auth*,                 // in
                     unsigned char**,           // out
                     uint8_t*                   // out
                    );

int DAuth_SignedHash_set (Daa_Auth*,            // in
                          unsigned char*,       // in
                          uint8_t               // in
                         );

int DAuth_SignedData_set (Daa_Auth*,            // in
                          unsigned char*,       // in
                          uint8_t               // in
                         );

int DAuth_Bname_set (Daa_Auth*,                 // in
                     unsigned char*,            // in
                     uint8_t                    // in
                    );

int DAuth_SignedData_get (Daa_Auth*,            // in
                          unsigned char**,      // out
                          uint8_t*              // out
                         );

int DAuth_SignedHash_get (Daa_Auth*,            // in
                          unsigned char**,      // out
                          uint8_t*              // out
                         );

int DAuth_Signature_get (Daa_Auth*,             // in
                         unsigned char**,       // out
                         uint8_t*               // out
                        );
int DAuth_verify_authentication (Daa_Auth*,     // in
                                 X509 *         // in
                                );
```

```
int DAuth_authentication_state (Daa_Auth* daa   // in
                               );

int DAuth_Signature_store (Daa_Auth*            // in
                          );

int DAuth_Signature_count (Daa_Auth*            // in
                          );

Daa_Auth * DAuth_DAA_anonym_auth_new (SSL*,     // in
                           Daa_Auth*            // in
                          );
```

Annex B (informative): code examples

B.1 Low level enhancement

B.1.1 Hello extensions

B.1.1.1 Simple example

Source code for the client application.

```
int cb_clnt (SSL *ssl, TLSEXT_GENERIC *ext) {
   /* Fetching context data */
   my_data_stuct ctx_data = ext->ssl_tlsext_ctx_data;

   /* Handling of the extension here */
   ...

   /* As example, just a print out */
   printf ("Received tls extension of type %d and length %d\n",
            ext->tlsext_type, ext->tlsext_data_length);

   for (i=0; i<ext->tlsext_data_length; i++) {
      printf ("%02x ", (ext->tlsext_data)[i]);
   }
   printf ("\n\n");
}

int main () {
   int type = ... /* type of the extension */
   int size = ... /* size of the extension */
   unsigned char data = ... /* payload of the extension */
   my_data_struct ctx_data = ... /* context data */

   ...

   /* OpenSSL standard stuffs here */
   if (!(ssl = SSL_new(ctx)))
      int_error("Error creating an SSL context");

   ...

   SSL_TLSEXT_client_create (ssl, type, len, data);
   SSL_TLSEXT_client_cb_set (ssl, type, &cb_clnt, ctx_data);

   ...

   if (SSL_connect(ssl) <= 0)
      int_error("Error connecting SSL object");

   /* Now the secure channel is established */
```

Source code for the server application.

```
int cb_srvr (SSL *ssl, TLSEXT_GENERIC *ext) {
   /* Fetching context data */
   my_data_stuct ctx_data = ext->ssl_tlsext_ctx_data;

   /* Handling of the extension here */
   ...

   /* As example, just a print out */
   printf ("Received tls extension of type %d and length %d\n",
            ext->tlsext_type, ext->tlsext_data_length);

   for (i=0; i<ext->tlsext_data_length; i++) {
      printf ("%02x ", (ext->tlsext_data)[i]);
   }
   printf ("\n\n");
}

int main () {
   int type = ... /* type of the extension */
   int size = ... /* size of the extension */
   unsigned char data = ... /* payload of the extension */
   my_data_struct ctx_data = ... /* context data */

   ...

   /* OpenSSL standard stuffs here */
   if (!(ssl = SSL_new(ctx)))
      int_error("Error creating an SSL context");

   ...

   SSL_TLSEXT_server_create (ssl, type, len, data);
   SSL_TLSEXT_server_cb_set (ssl, type, &cb_srvr, ctx_data);

   ...

   if (SSL_accept(ssl) <= 0)
      int_error("Error accepting SSL connection");

   /* Now the secure channel is established */
}
```

B.1.1.2 Improved example

The code for the client and for the server are very similar in the previous example. While the previous code works, it can be slightly improved. In the example, the server creates the extensions before accepting the connection. If the client did not send the same extension in the client hello, then the server would break the RFC specification (by sending an extension that was not requested by the client), leading to the end of the handshake. This can be avoided by defining the extension for the server only if a client hello with that extension was received. In order to do this, the

```
SSL_TLSEXT_server_create (ssl, type, len, data);
```

must be moved inside the callback function. The resulting code for the server is:

```
int cb_srvr (SSL *ssl, TLSEXT_GENERIC *ext) {
   /* Fetching context data */
   my_data_stuct ctx_data = ext->ssl_tlsext_ctx_data;

   /* The server received the extension,
    * hence is can safely send it back
    * to the client
    */
   SSL_TLSEXT_server_create (ssl, type, len, data);

   /* Handling of the extension here */
   ...

   /* As example, just a print out */
   printf ("Received tls extension of type %d and length %d\n",
            ext->tlsext_type, ext->tlsext_data_length);

   for (i=0; i<ext->tlsext_data_length; i++) {
      printf ("%02x ", (ext->tlsext_data)[i]);
   }
   printf ("\n\n");
}

int main () {
   int type = ... /* type of the extension */
   int size = ... /* size of the extension */
   unsigned char data = ... /* payload of the extension */
   my_data_struct ctx_data = ... /* context data */

   ...

   /* OpenSSL standard stuffs here */
   if (!(ssl = SSL_new(ctx)))
      int_error("Error creating an SSL context");

   ...

   SSL_TLSEXT_server_cb_set (ssl, type, &cb_srvr, ctx_data);

   ...

   if (SSL_accept(ssl) <= 0)
      int_error("Error accepting SSL connection");

   /* Now the secure channel is established */
```

B.1.2 Supplemental data

B.1.2.1 Simple example

Source code for the client application.

```
int my_prepare_clnt (SSL *ssl, void *ctx_data) {
   my_data_stuct *c_data = (my_data_struct) ctx_data;
   unsigned char *data;

   /* Do anything need with context data in order
    * to define the type, the len and the payload
    */
   type = ... ;
   len = ... ;
   data = ... ;

   /* We add the supplemental data to the list
    * of supplemental data to be sent
    */
   SSL_SUPPL_DATA_push (ssl, type, len, data);
}

int suppl_data_handle_clnt (SSL *ssl, int type,
             unsigned char *data, int len, void * ctx_data) {

   /* Handling the supplemental data entry here...
    * Just a print out as example
    */
   printf ("Received suppl data of type %d and size %d\n",
                        type, len);

   for (i=0; i<len; i++) {
      printf ("%x ", *(data++));
   }
   printf ("\n");
}

int main () {
   int type = ... /* type of the supplemental data */
   my_data_struct ctx_data = ... /* context data */

   ...

   /* OpenSSL standard stuffs here */
   if (!(ssl = SSL_new(ctx)))
      int_error("Error creating an SSL context");

   ...
   SSL_SUPPL_DATA_prepare_set
             (ssl, &my_prepare_clnt, ctx_data);
   SSL_SUPPL_DATA_cb_set
```

```
                (ssl, type, &suppl_data_handle_clnt, ctx_data);
    ...

    if (SSL_connect(ssl) <= 0)
       int_error("Error connecting SSL object");

    /* Now the secure channel is established */
 }
```

Source code for the server application.

```
 int my_prepare_srvr (SSL *ssl, void *ctx_data) {
    my_data_stuct Oggi,*c_data = (my_data_struct) ctx_data;
    unsigned char *data;

    /* Do anything need with context data in order
     * to define the type, the len and the payload
     */
    type = ... ;
    len = ... ;
    data = ... ;

    /* We add the supplemental data to the list
     * of supplemental data to be sent
     */
    SSL_SUPPL_DATA_push (ssl, type, len, data);
 }

 int suppl_data_handle_srvr (SSL *ssl, int type,
                unsigned char *data, int len, void * ctx_data) {

    /* Handling the supplemental data entry here...
     * Just a print out as example
     */
    printf ("Received suppl data of type %d and size %d\n",
                          type, len);

    for (i=0; i<len; i++) {
       printf ("%x ", *(data++));
    }
    printf ("\n");
 }


 int main () {
    int type = ... /* type of the supplemental data */
    my_data_struct ctx_data = ... /* context data */

    ...

    /* OpenSSL standard stuffs here */
    if (!(ssl = SSL_new(ctx)))
```

```
      int_error("Error creating an SSL context");

    ...
    SSL_SUPPL_DATA_prepare_set
              (ssl, &my_prepare_srvr, ctx_data);
    SSL_SUPPL_DATA_cb_set
              (ssl, type, &suppl_data_handle_srvr, ctx_data);
    ...

    if (SSL_accept(ssl) <= 0)
       int_error("Error accepting SSL connection");

    /* Now the secure channel is established */
 }
```

B.1.2.2 Improved example

Any supplemental data entry must be negotiated using the TLS hello extensions. Receiving a supplemental data entry that was not negotiated, brings to a fatal error, and the receiver must close the connection.

An overall example that uses the hello extensions to negotiate a supplemental data message is shown below.

Source code for the client application.

```
 int my_prepare_clnt (SSL *ssl, void *ctx_data) {
    my_data_stuct *c_data = (my_data_struct) ctx_data;
    unsigned char *data;

    /* Do anything need with context data in order
     * to define the type, the len and the payload
     */
    type = ... ;
    len = ... ;
    data = ... ;

    /* We add the supplemental data to the list
     * of supplemental data to be sent
     */
    SSL_SUPPL_DATA_push (ssl, type, len, data);
 }

 int suppl_data_handle_clnt (SSL *ssl, int type,
             unsigned char *data, int len, void * ctx_data) {

    /* Handling the supplemental data entry here...
     * Just a print out as example
     */
    printf ("Received suppl data of type %d and size %d\n",
                        type, len);

    for (i=0; i<len; i++) {
```

```
      printf ("%x ", *(data++));
   }
   printf ("\n");
}

int cb_clnt (SSL *ssl, TLSEXT_GENERIC *ext) {
   /* Fetching context data */
   my_data_stuct ctx_data = ext->ssl_tlsext_ctx_data;

   SSL_SUPPL_DATA_prepare_set
             (ssl, &my_prepare_clnt, ctx_data);
   SSL_SUPPL_DATA_cb_set
             (ssl, type, &suppl_data_handle_clnt, ctx_data);
}

int main () {
   int type = ... /* type of the extension */
   int size = ... /* size of the extension */
   unsigned char data = ... /* payload of the extension */
   my_data_struct ctx_data = ... /* context data */

   ...

   /* OpenSSL standard stuffs here */
   if (!(ssl = SSL_new(ctx)))
      int_error("Error creating an SSL context");

   ...

   SSL_TLSEXT_client_create (ssl, type, len, data);
   SSL_TLSEXT_client_cb_set (ssl, type, &cb_clnt, ctx_data);

   ...

   if (SSL_connect(ssl) <= 0)
      int_error("Error connecting SSL object");

   /* Now the secure channel is established */
}
```

Source code for the server application.

```
int my_prepare_srvr (SSL *ssl, void *ctx_data) {
   my_data_stuct *c_data = (my_data_struct) ctx_data;
   unsigned char *data;

   /* Do anything need with context data in order
    * to define the type, the len and the payload
    */
   type = ... ;
   len = ... ;
   data = ... ;
```

```
   /* We add the supplemental data to the list
    * of supplemental data to be sent
    */
   SSL_SUPPL_DATA_push (ssl, type, len, data);
}

int suppl_data_handle_srvr (SSL *ssl, int type,
             unsigned char *data, int len, void * ctx_data) {

   /* Handling the supplemental data entry here...
    * Just a print out as example
    */
   printf ("Received suppl data of type %d and size %d\n",
                       type, len);

   for (i=0; i<len; i++) {
      printf ("%x ", *(data++));
   }
   printf ("\n");
}

int cb_srvr (SSL *ssl, TLSEXT_GENERIC *ext) {
   /* Fetching context data */
   my_data_stuct ctx_data = ext->ssl_tlsext_ctx_data;

   /* The server received the extension,
    * hence is can safely send it back
    * to the client
    */
   SSL_TLSEXT_server_create (ssl, type, len, data);

   SSL_SUPPL_DATA_prepare_set
             (ssl, &my_prepare_srvr, ctx_data);
   SSL_SUPPL_DATA_cb_set
             (ssl, type, &suppl_data_handle_srvr, ctx_data);
}

int main () {
   int type = ... /* type of the extension */
   int size = ... /* size of the extension */
   unsigned char data = ... /* payload of the extension */
   my_data_struct ctx_data = ... /* context data */

   ...

   /* OpenSSL standard stuffs here */
   if (!(ssl = SSL_new(ctx)))
      int_error("Error creating an SSL context");

   ...
```

```
    SSL_TLSEXT_server_cb_set (ssl, type, &cb_srvr, ctx_data);

    ...

    if (SSL_accept(ssl) <= 0)
       int_error("Error accepting SSL connection");

    /* Now the secure channel is established */
 }
```

B.2 DAA anonymous authentication

Source code for the client application.

```
/* Needed variables */
unsigned char * signed_data = ... ;
uint16_t signed_data_len = ... ;

unsigned char * signed_hash = ... ;
uint8_t signed_hash_len = ... ;

/* Creation of the TSS objects here ... */

/* Creating the DAA object */
Dauth * daa = Dauth_new (PLATFORM);

/* Passing the necesasry parameters */
Dauth_SignedData_set (daa, signed_data, signed_data_len);
Dauth_SignedData_set (daa, signed_hash, signed_hash_len);

/* Creating SSL context */
if (!(ssl = SSL_new(ctx)))
   int_error("Error creating an SSL context");

Dauth_DAA_anonym_auth_new (ssl, daa);

/* Standard OpenSSL TLS connection here */
SSL_connect (ssl);
```

Source code for the server application.

```
/* Needed variables */
unsigned char * basename = ... ;
uint8_t basename_len = ... ;

/* Client certificate */
X509 *cert = NULL;



/* Creation of the TSS objects here ... */
```

```
/* Creating the DAA object */
Dauth * daa = Dauth_new (VERIFIER);

/* Passing the necesasry parameters */
Dauth_Basename_set (daa, basename, basename_len);

/* Creating SSL context */
if (!(ssl = SSL_new(ctx)))
   int_error("Error creating an SSL context");

Dauth_DAA_anonym_auth_new (ssl, daa);

/* Standard OpenSSL TLS connection here */
SSL_accept (ssl)

/* Verify anonymous authentication */
cert = SSL_get_peer_certificate (ssl); /*Getting client certificate*/
Dauth_verify_authentication (daa, cert);
if (Dauth_authentication_state (daa) != Authenticated)
   int_error ("Error verifying the DAA authentication");

...
```

D03d.1 JAVA High Level overview

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Report (see p 84/85 Annex 1 - Nature)

Deliverable reference number	IST-027635/D3.1/RC1
Deliverable title	JAVA High Level overview
WP contributing to the deliverable	WP3
Due date	JUL2007
Actual submission date	

Responsible Organisation	IAIK
Authors	IAIK
Abstract	The Java programming language and related technologies have undergone a broad adoption ranging from large-scale business applications hosted in dedicated data centers to resource constrained environments as found in mobile phones or Personal Digital Assistants (PDAs). Java programs are not compiled to native machine code but to a special form of intermediate code, called byte code. This byte code is then executed by a virtual machine (VM) called the Java VM. This characteristic makes Java an excellent choice for development aiming at heterogenous environments as for example grid computing provides.
Keywords	TPM, TSS, JAVA, Virtualisation, TC enhanced JAVA

Dissemination level	Public
Revision	RC1

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

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WP03d.1: Java Integration – Highlevel Overview

revision 2.0
Institute for Applied Information Processing and Communications (IAIK), Technical University Graz

Work package 03d focuses on the integration of Trusted Computing (TC) technology into the Java programming language. This section outlines the importance of this work and presents an overview of the individual aspects addressed as part of this work package.

1.1 The Role of Java

The Java programming language and related technologies have undergone a broad adoption ranging from large-scale business applications hosted in dedicated data centers to resource constrained environments as found in mobile phones or Personal Digital Assistants (PDAs). Java programs are not compiled to native machine code but to a special form of intermediate code, called byte code. This byte code is then executed by a virtual machine (VM) called the Java VM. This characteristic makes Java an excellent choice for development aiming at heterogenous environments as for example grid computing provides.

In contrast to other programming languages such as C or C++, Java is equipped with inherent security features supporting the development of more secure software. Among those features are automatic array-bounds checking and garbage collection. These features help to avoid common problems such as buffer overflows or memory leaks. Additional aspects that distinguish Java from other environments are code-signing mechanisms and the verification of code when it is loaded.

1.2 Integration of Trusted Computing into Java

With the advent of Trusted Computing (TC) as envisioned by the Trusted Computing Group (TCG), it becomes possible to further enhance Java in terms of security. As a first step, it is required to provide simple mechanisms for Java developers to access the functionality provided by the Trusted Platform Module (TPM) and the TCG Software Stack (TSS).

Note that the TSS not only exposes a software interface to access the functionality of the TPM, but also features more complex operations, which are typically combining several basic functions. Amongst others, the TSS provides functions to generate cryptographic keys and signatures. Furthermore, it provides functions to measure and attest the state of a platform and to cryptographically protect data via sealing and binding functions.

The TSS itself is designed to be implemented using the C programming language and thus offers a very straightforward way to call each function. In the Java environment a programming interface is expected to be an object oriented Application Programming Interface (API). To enable the use of the TSS functionality from Java, additional layers have to be introduced. Illustration 1 depicts a possible implementation, giving an overview of the stacked layers from highest abstraction (Java) down to the hardware. Each layer transforms and adapts calls to the next layer, offering functionality as possible by the specific environment constraints.

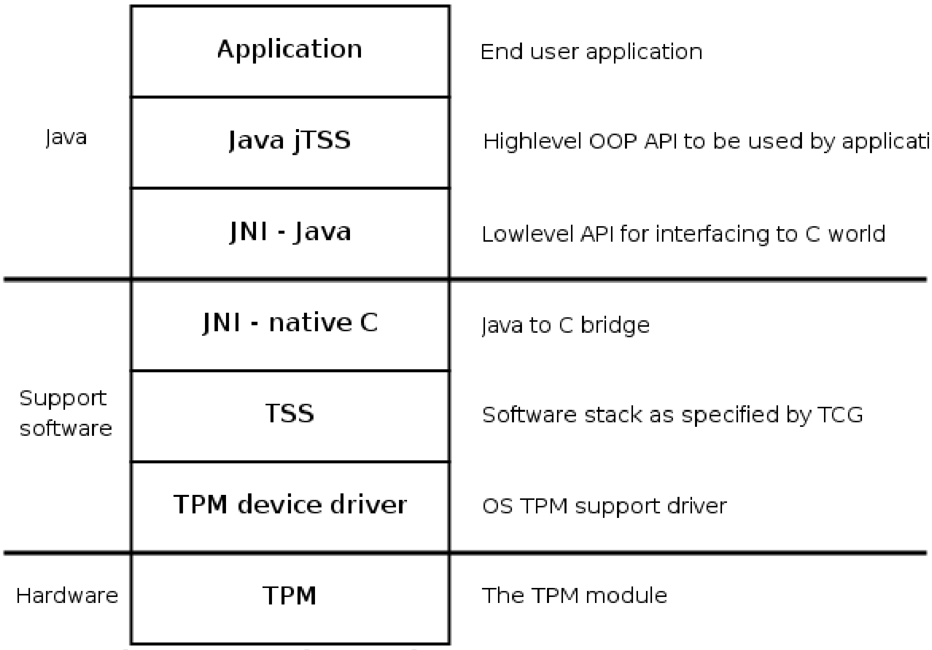

Illustration 1: TSS Abstraction Layers

In order to allow access not only to the local TSS but also to trusted environments located on remote machines, the Java TSS API has to implement a remote procedure call mechanism. Conforming to the TSS 1.2 specification, this facility will be based on the Simple Object Access Protocol (SOAP) ensuring interoperability with TSS implementations from different vendors running on a variety of platforms. The two ways to access the TSS from Java (local API calls and SOAP) are presented in Illustration 2.

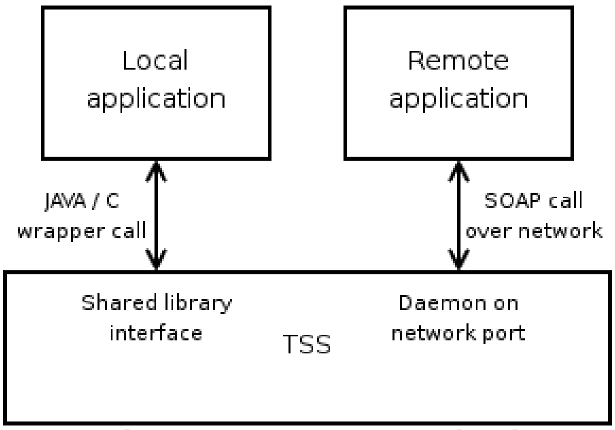

Illustration 2: TSS Access Mechanisms

Java integration, as planned for the OpenTC project, will go beyond simply allowing Java developers to access TPM and TSS functionality. The features of the TC architecture will be used to extend the trust and security provided by the underlying operating systems to the Java VM and its applications. A fundamental part of the TCG specification is the creation of a chain of trust that is rooted in the TPM and its surrounding trusted building blocks. These building blocks include the core root of trust for measurement which measures the BIOS before it hands over control to it. The measurements, which actually are cryptographic hashes of the code, are securely stored in the TPM. The chain of trust is continued up to the operating system and application level. In fact, a Java VM is nothing else but an application that is executed by the operating system. After control has been passed to the Java VM, it is up to the VM to enforce TC features. Java allows to dynamically load additional code in the form of classes at runtime. Consequently, the class loading mechanisms have to be extended in such a way that all loaded classes get measured and the hash values are stored in the platform configuration registers of the

TPM. This measuring however is not limited to classes loaded from local storage. Other variations of dynamically loaded code such as Java Applets have to be taken into account. Additionally, the behavior and trustworthiness of applications can considerably be influenced by configuration files or external scripts processed by the application. Therefore, these aspects have to be considered as well as native code. With the Java Native Interface (JNI), developers are able to write native libraries which can be loaded by the Java VM. Not all these goals can be achieved by modifications and extensions of the Java class library. Additionally, enhancements of the VM itself are required. Illustration 3 shows the chain of trust, beginning by the root of trust and ending in the dynamically loaded classes.

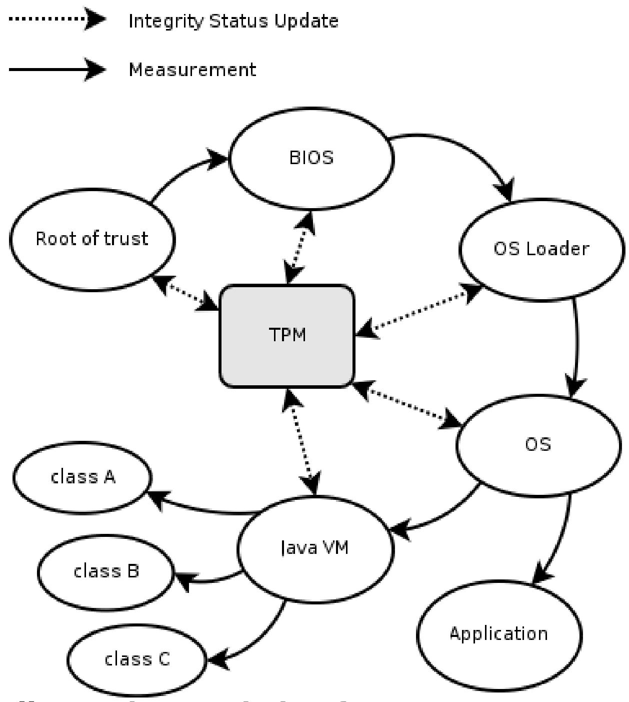

Illustration 3: Chain of Trust

1.3 Network Security and Isolation of Security-Critical Applications

Remote attestation - which means that a remote party is able to verify that a platform is in a specific state regarding the applications it is executing - is one of the core issues of Trusted Computing. It allows a remote party, such as an Internet-merchant, to verify that it is communicating with a valid customer and that the machine of the customer is in a proper state – e.g. not infected with viruses or worms that could illegally interfere with a business transaction. At the same time, the customer significantly benefits from trusted computing because it enables him to undoubtedly verify that the merchant is the one he claims to be. Additionally, the customer can ensure that the server of the merchant was not manipulated by a third party in order to reveal sensitive information. Remote attestation as well as verification mechanisms have to be made available to Java.

Aside from verifying the state of the connection partners, the protection of network connections is an important topic. This topic is addressed by the Trusted Network Connect (TNC) working group of the TCG. As part of this effort, Transport Layer Security (TLS) Attestation is specified providing an extension to the currently deployed TLS protocol. The secure network communication facilities already present in Java will be enhanced to take advantage of TLS attestation.

Securing an entire general purpose operating system might not always be practical or feasible. With the availability of virtualization technologies, it becomes possible to establish secure and isolated compartments within one physical machine. While a legacy operating system is running in an untrusted compartment, a secure application for doing sensitive transactions over the network can be executed in another, secure compartment. Java could significantly benefit from that approach by running the Java VM in such a compartment. This allows to keep the underlying hardware abstraction and operating system layer as small as possible. By minimizing the secure code base, the complexity of measurement and remote attestation is greatly reduced. Notwithstanding, the TC enhanced Java environment will be able to run in a striped-down, special-purpose compartment as well as on full featured operating systems.

1.4 Applicability of TC-Enhanced Java

As mentioned before, Java is used for network oriented applications such as grid computing or any kind of web service. This type of application will especially benefit from the integration of TC capabilities into Java environments. For the first time, it becomes possible to establish trust in properties of communication partners that is not only based on software but rooted in a trusted piece of hardware.

Other kinds of application that are gaining more and more momentum across Europe are e-Government and e-Commerce applications. They cover various areas such as civil services like financial management, health services, netbanking or e-voting which require a very high level of trust and security.

In order to demonstrate the benefits of TC in combination with Java a proof-of-concept prototype will be developed. A reasonable demonstrator could be for example an adaption of the Austrian Security-Layer framework to the features of TC. Other prototypes could show for example the use of trusted computing in the areas of grid computing, peer-to-peer applications or any kind of distributed computing.

Integrating Trusted Computing into the Java Programming Language

D03.d2: VM for TCP integration design specification

D03.d3: Java API and library integration design document

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Internal Specification

Responsible Organisation	IAIK
Authors	IAIK (Markus Demuth, Kurt Dietrich, Jürgen Malin, Peter Lipp, Martin Pirker, Thomas Winkler)

Dissemination level	Internal Deliverable
Revision	1

Revision Sheet

ReleaseNo	Date	Revision Description
1	04.12.2006	Initial release

Table of Contents

1 Introduction

This deliverable deals with the design of the integration of Trusted Computing into the Java programming language environment. The Java programming environment has seen a broad adoption ranging from large-scale business applications hosted in dedicated data centers to resource constrained environments as found in mobile phones or Personal Digital Assistants (PDAs). Java programs are not compiled to native machine code but to a special form of intermediate code, called byte code. This byte code is then executed by a virtual machine (VM) called the Java VM. This characteristic makes Java an excellent choice for development aiming at heterogeneous environments as for example grid computing.

In contrast to conventional programming languages such as C or C++, Java is equipped with inherent security features supporting the development of more secure software. Among those features are automatic array-bounds checking and garbage collection. These features help to avoid common problems such as buffer overflows or memory leaks. Additional aspects that distinguish Java from other environments are code-signing mechanisms and the verification of byte code when it is loaded.

Note: This is a preliminary version of this deliverable. Due to massive involvement into the demonstrator prototype work, some of the work behind this deliverable is still ongoing. During 2007 an updated version will be made available. Also, deliverables D03d.2 (VM for TCP integration design specification) and D03d.3 (Java API and library integration design document) have been combined into one deliverable for practicability purposes. The final version may be delivered in form of separate documents again.

1.1 Areas of Applications for Trusted Computing enhanced Java

This section tries to identify two exemplary areas of application that could benefit from a trusted computing enhanced Java environment. The first area are business environments that highly depend on secure trustworthy infrastructure. The other one are network centric applications deployed on a large number of machines.

Over time, Java has become one of the major development environments for business applications. Many enterprises rely on Java technology and large amounts of money and work have been spent on building Java frameworks. This commercial business environment is one of those fields where trusted computing technologies are expected to see first deployments. Businesses that highly depend on the security and trustworthiness of computer systems are e.g. financial service providers. The wide deployment of Java based software in this area and the need for trustworthy computing systems are one reason why the integration of Trusted Computing into Java is of high importance.

Another area of application is network based software. By its nature, Java applications can be executed on any platform a virtual machine is available for. This is one reason why Java is a logical choice for highly networked applications that are deployed in heterogeneous environments. On of these areas currently facing a large interest is grid computing. The idea of grid computing is to offer computing resources to others. By bundling these resources, users are enabled to solve highly complex computations which otherwise could not be solved or would require a dedicated computing infrastructure. Since the users of a grid are unaware of the environment of the machines that are actually doing the computations, mechanisms are required that ensure a certain level of trustworthiness of these machines. With the availability of Trusted Computing technologies in Java, mechanisms ensuring this trustworthiness can be implemented.

1.2 Scope of Trusted Computing Integration into Java

The wide spread use of Java in commercial environments as well as the already existing security features make Java an excellent choice to be enhanced with trusted computing functionality. The individual aspects addressed as part of OpenTC work package 03d are:

- **Making Trusted Computing Functionality available to a Java developers:**
The Trusted Computing Group (TCG) not only specifies Trusted Platform Modules (TPMs) but also an accompanying software infrastructure called the TCG Software Stack (TSS). This stack is defined as a system service to be implemented using the C programming language. It offers a flat C interface for applications to access the TPM and its functionality. One goal of this work package is to make the services of the TSS available to Java developers in a consistent and object oriented way. Section 2 is dedicated to the topic of accessing the TPM and TSS from within Java.
- **Enhancing the Java virtual machine with Trusted Computing:** The Java virtual machine by design is offers security features such as byte code verification or signed code. Section 3 presents who a Java VM can be modified such that the chain of trust, rooted in the CRTM and the TPM, can be extended to Java applications. This involves an evaluation of potential open source Java virtual machines as well as considerations related to modifications of the Java class loading process such that Java applications become part of the chain of trust.
- **Adding Trusted Computing enhanced networking functionality to Java:** An important aspect of TCG's efforts towards a more trustworthy computing environment is the attestation of the configuration of a platform. Apart from establishing the chain of trust by measuring all applications that are executed on a platform, this also requires secure and standardized ways of how to report these measurements to interested parties. Section deals with attestation and other networking related aspects and details how attestation can be made available to Java applications.

2 TSS and TPM Access from Java

This chapter is dedicated to all aspects related to accessing the Trusted Platform module (TPM) and the TCG Software Stack (TSS) from within Java. The Trusted Computing Group (TCG) specifies the TSS as the default mechanism for applications to interact with the TPM. In addition to passing application requests to the TPM, the TSS provides a number of other services such as managing concurrent TPM access or providing a persistent storage for cryptographic keys generated inside the TPM.

Before addressing aspects of making TSS functionality available to Java, section 2.1 will provide an overview of the TSS architecture and its functionality.

2.1 TCG Software Stack Overview

TPMs are designed as low cost devices providing protected storage and protected capabilities. Due to their inexpensive nature, the internal resources and external interfaces provided by TPMs are kept to a minimum. To nevertheless provide a certain level of usability and functionality, the TCG defines the TSS. Functions that require protected capabilities are implemented in the TPM while non-sensitive features which do not require hardware protection are implemented in software. To allow a standard

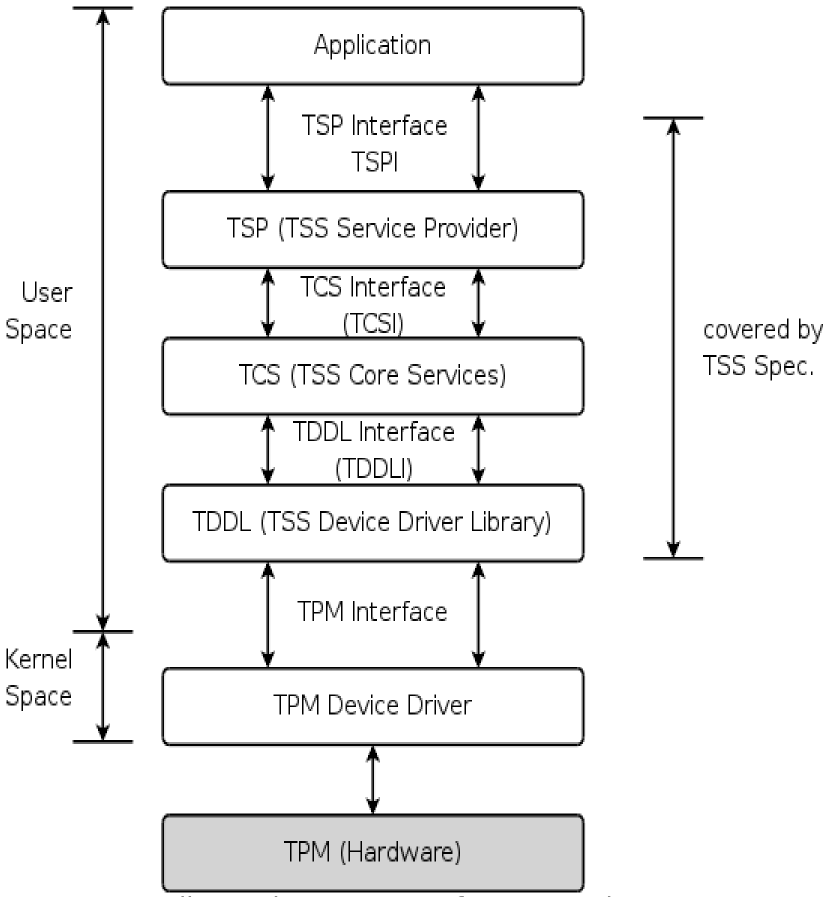

Illustration 1: TCG Software Stack Layers

way to access Trusted Computing functionality, these software components are combined into the TSS offering standardized interfaces. This way, the TCG intends to provide a standard environment for applications.

For the TSS, the TCG choose a layered architecture where higher layers provide higher abstractions of the Trusted Computing functions. Illustration 1 presents an overview of the individual TSS layers.

2.1.1 TPM (Hardware)

In case of the PC platform, the hardware TPM is soldered onto the mainboard and can not easily be removed or replaced. It typically is connected to the rest of the system via the LPC bus.

2.1.2 TPM Device Driver (TDD)

The TPM device driver resides in Kernel space. For 1.1b TPMs, this driver is vendor specific since the TPM is equipped with a proprietary interface. For 1.2 TPMs, there also is a generic device driver available called TIS (TPM Interface Specification) driver. TIS provides a generic, vendor independent interface to access TPM functionality. Depending on the platform and operating system, the TDD may provide additional functionality such as power management.

2.1.3 TSS Device Driver Library (TDDL)

The TDDL (Trusted Device Driver Library) is located in user space. From the user's point of view it exposes an OS and TPM independent set of functions that allows basic interaction with the TPM. This includes sending commands in the form of byte streams to the TPM and receiving the TPM's responses. The intention of the TDDL is to offer a standard TPM interface regardless of the fact who manufactured the TPM and the accompanying TPM device driver. This ensures that different TSS implementations can communicate with any given TPM. To make that possible, the TCG specifies the TDDL interface (TDDLI) which is a required set of functions to be implemented by the TDDL. In contrast to that, the communication between the TDDL and the TPM is vendor specific.

The TDDL is designed to be a single-instance, single-threaded component. The TCS are responsible for proper command serialization.

2.1.4 TSS Core Services (TCS)

The Trusted Core Services (TCS) are defined to be implemented as a system service. There only is one TCS instance for a TPM. For communication with the TPM it relies on the TDDL and ensures that commands are sent to the TPM properly serialized. For the TCS, the TCG specifies a C style interface called TCS interface (TCSI).

The main functionalities implemented in the TCS are:

- **Key Management and Persistent Storage:** Cryptographic keys generated by the TPM are not intended to be stored permanently inside the TPM. Due to the low cost nature of the TPM, it's internal memory is limited. Therefore keys that are not only temporarily used have to be stored securely in a persistent storage outside the TPM. The key management component of the TSS is responsible to manage this storage. When creating a key inside the TPM, the user has to provide a parent key. At the time such a key leaves the TPM and is written to the persistent storage, the key is encrypted using the parent key. This encryption is taking place inside the TPM and consequently, no key leaves the TPM in an unencrypted form. The key forming the root of this key hierarchy is the storage root key (SRK) which is permanently stored inside the TPM.

- **Key Cache Management:** To be able to use a key inside the TPM, it has to be ensured that the key is loaded in one of the key slots of the TPM. The number of key slots is limited. To avoid that application developers or users have to keep track of how many key slots have already been used, the key cache manager has the responsibility to unload keys from the TPM if the available space is depleted. This process is transparent to the user. If e.g. a user key has been swapped out, the key cache manager will load it into the TPM the next time the user makes use of the key. Since the key handle held by the user remains the same, this entire process is transparent to the user.
- **TPM Command Generation:** Commands are sent as byte streams to the TPM. The command generation component of the TSS is responsible for assembling these commands.
- **Communication Mechanisms:** Access to the services of the TCS can be provided in two different ways: Via Remote Procedure Calls (RPCs) oder via SOAP. Please refer to section 2.2 for further details.

2.1.5 TSS Service Provider (TSP)

The TSS Service Provider (TSP) is the component that provides TCG services to applications. Typically, the TSP is implemented as a shared library that is directly linked to the application. Interaction with the TCS takes place via an inter process communication mechanism such as RPC. The TSP is required to provide a standardized TSP interface (TSPI). TCG defines the TSPI interface as a C style API but with object orientation in mind.

2.2 TSS Communication Mechanisms

The standard interface of the TSS for applications is the TDDL interface. Applications can directly link to the TDDL library and use this interface to access the TPM. Via the

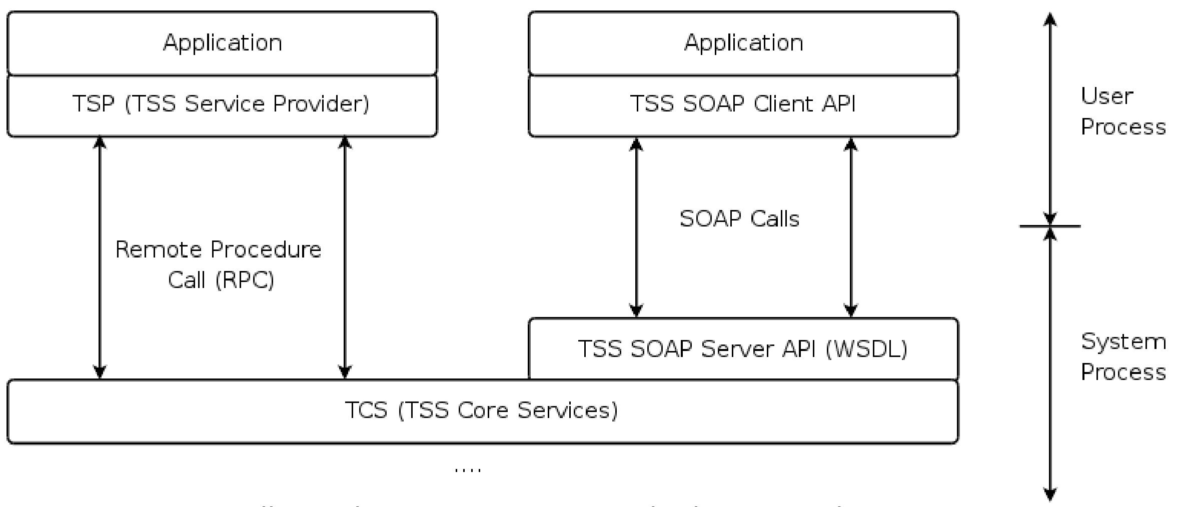

Illustration 2: TSS Access methods: RPC and SOAP

TDDL library, the application can not only access the local TSS but also remote TSSs. Interaction between the TDDL and the TCS is specified to be implemented based on Remote Procedure Calls (RPC). The actual RPC mechanism as well as the marshalling and unmarshalling of data sent to and received from the TCS is vendor specific.

As a consequence, the RPC mechanism of the TSS does not ensure interoperability between stacks of different vendors.

To overcome this limitation, TCG defines an alternative interface for the TCS which is agnostic to the platform and the programming language used to implement the TSS. This interface is based on the Simple Object Access Protocol (SOAP) version 1.1 using HTTP as transport protocol. The functionality that has to be exposed by this interface is defined in the form of a Web Service Description Language (WSDL) file provided by the TCG. The approach of using a standardized and platform independent interface is envisioned to ensure interoperability between stacks of different vendors.

2.3 Java TSS Bindings

The goal this effort is to make the TSS functionality described in the previous sections accessible to Java applications. As outlined before, there are two basic approaches for interacting with the TCS of the TSS: RPC based communication using the TDDL and SOAP using the SOAP service provided by the TCS.

To support a broad variety of TSS implementations, botch approaches should be supported by the Java TSS bindings (alternatively also referred to as Java TSS Wrapper).

2.3.1 Java TSS Bindings Architecture

To enable the use of the TSS functionality in Java, additional layers have to be introduced on top of the existing TSS layers. Illustration 3 presents an overview of the chosen approach.

These additional layers are drawn as blue and orange boxes in Illustration 3. The blue layer represents the high level Java API that is used by application.

The orange boxes denote implementation components that are specific to the

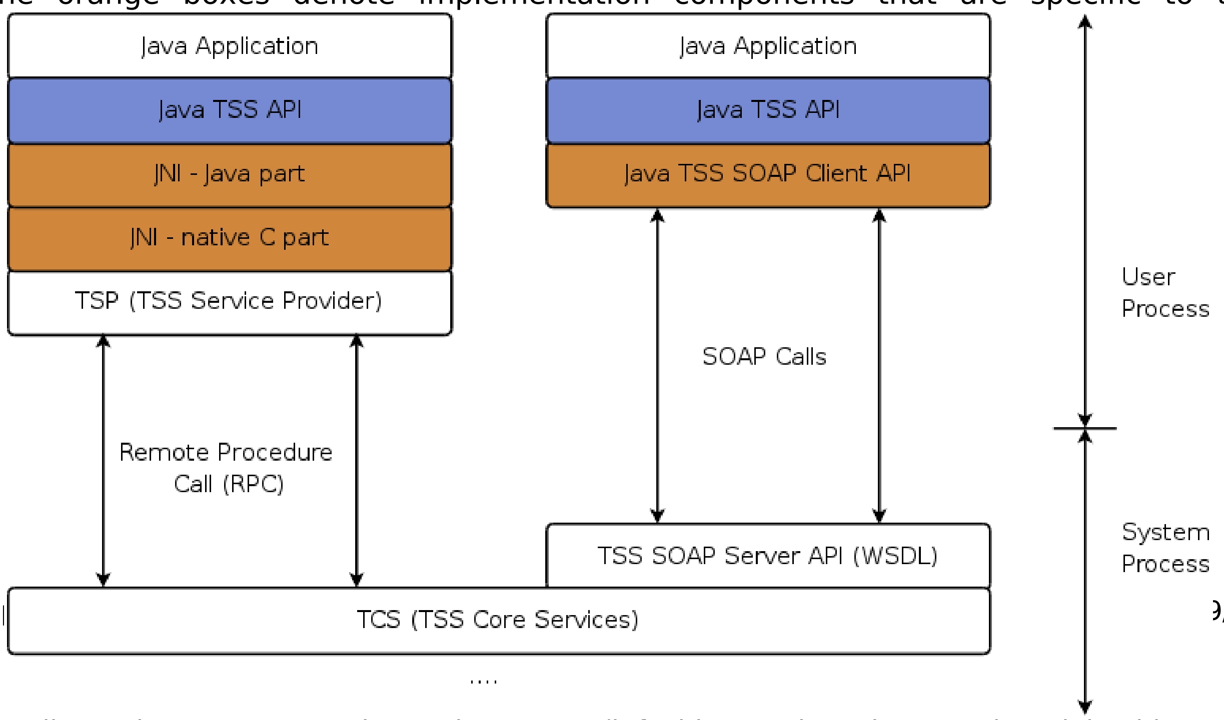

Illustration 3: Java TSS Abstraction Layers (left side: RPC based connection, right side: SOAP based connection)

connection mechanism used to interact with the TCS. According to the TSS specification this can be a vendor specific RPC call mechanism or a standardized Simple Object Access Protocol (SOAP) API. For Windows operating system, the TSS specification also mentions a COM (Component Object Model) interface without going into further details.

2.3.2 Detailed Design Aspects

This section is dedicated to a more detailed discussion of certain design aspects of the Java TSS Wrapper.

To allow a high degree of flexibility, the design is split into two parts: The Java TSS frontend and connection backends that are responsible for the actual connection to the TCS. Illustration 4 presents an overview of this architecture. Components belonging to the frontend have a blue background while backend components have and orange background.

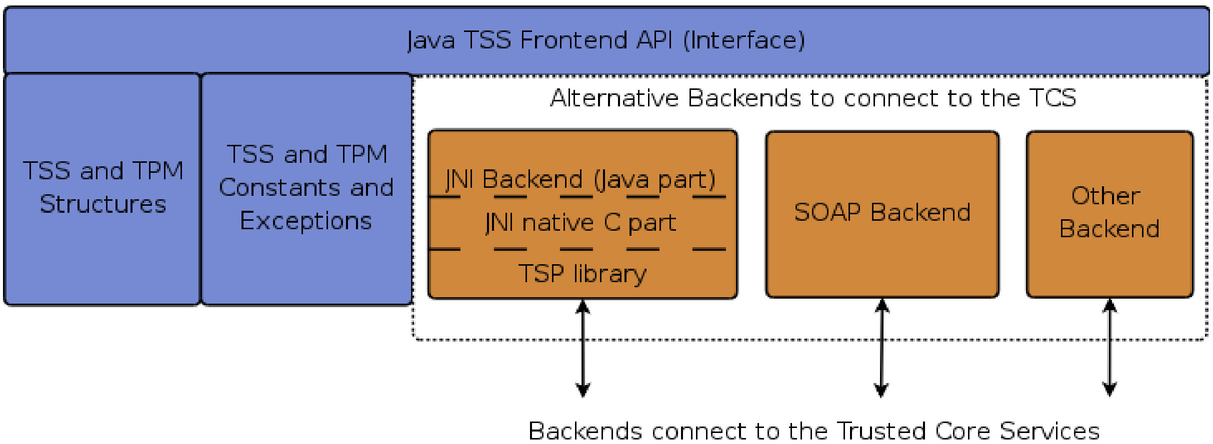

Illustration 4: The Java TSS Wrapper is split into frontend components (blue) and different backend implementations (orange).

- **Frontend Components**

  The main part of the frontend components is the Java TSS Frontend API which is implemented as a Java interface. This interface provides all functionality required by Java developers to access the TSS. This interface is the same, no matter what the actual mechanism for communication with the TCS is (RPC, SOAP, ...). This way, a Java application that is accessing the TSS does not have to be modified in case the underlying TCS connection mechanism is changed.

  The frontend interface is designed to be similar to the standardized TSP interface for two reasons: Developers already familiar with the TSPI should be able to use the Java bindings without steep learning curve. Reason number two is that an interface similar to that of the TSPI provides all the flexibility of the underlying stack to Java developers. Existing resources, such as TSPI based demo code, can therefore more easily be mapped to Java.[1]

1 The TSPI, and consequently its Java equivalent, offers the full range of functionality provided

While the basic concepts and functionality of the native TSP remains the same in its Java counterpart, several aspects have been adopted to meet the object oriented nature of Java: All TSS entities such as contexts, keys, hashes or the TPM are represented by actual Java objects relieving the developer from managing object handles as it is required in the original TSP.

The following interface classes form the core of the API[2]:

- **TcIContext**

  A context represents a connection to the TSS core services. Since the TCS can be executed locally or remote, the context allows to specify the host to connect to.

  The context is used to created all further TSS objects (e.g. keys or policy objects). Moreover, the context is the entity that is used to access the TSS's persistent storage: The context provides functions to register, load or unregister keys from the persistent storage.

  The context is also responsible for housekeeping tasks such closing objects (releasing their handles), getting information (capabilities) about the TCS as well as freeing TSS memory.

  Memory for structures allocated by the TSS typically have to be freed by the application that has done the call. The Java TSS wrapper copies data received from the TSS into Java objects and releases TSS memory before returning the newly constructed Java objects to the caller. Thereby, Java developers a relieved from the need to explicitly free TSS memory.

- **TcITPM**
  The TPM, and parts of its functionality, is represented by this class. It provides functionality to take or clear TPM ownership, read and set the TPM status, obtain random numbers from the TPM or read and extend PCR registers. Aside from providing low level functions to e.g. trigger a TPM self test, it offers functions to create “attestation identities” and doing quote operations to attest the current state of the platform represented by the contents of the PCR registers.

- **TcIRsaKey**

  Instances of this class represent keys in the TPM's key hierarchy. It provides functionality to create a new key, to load a key into a key slot of the TPM or to certify keys.

- **TcIEncData**

  This class provides access to the TPM's bind/unbind and seal/unseal functions. By binding, data is encrypted using a TPM key. If this key is not

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by the TSS. While this is desired (and required) for sophisticates Trusted Computing applications, developers new to trusted computing might be overwhelmed. It therefore might be beneficial to add an additional, simplified interface on top of the Java TSS frontend that provides a set of well defined functions covering typical trusted computing usage scenarios. Since there is no broad experience with trusted computing applications yet, this topic is to be addressed at a later time.

2 Note that the current API design is focused towards 1.1b TCG Software Stacks. As 1.2 stacks become available, the design will be extended to cover 1.2 functionalities (see also section 2.4).

migratable, the only entity that is able to unbind (i.e. decrypt) the key is the TPM that holds the private key. Sealing takes this concept a step further: When sealing data, the platform configuration is included in the seal operation. By that, the sealed data can only be unsealed if the platform is in the state specified when sealing the data. The platform configuration is represented by the contents of the TPM's PCRs.

- **TcIHash**

  This class provides access to the TSS's hashing functions. That includes hash calculation, hash verification as well as creating signatures of data blocks using a TPM key.

- **TcIPcrComposite**

  The platform configuration registers (PCRs) can e.g. be used to attest the state of a platform (quote operation) or to seal data to a specific configuration. Instances of this class are used to select one or more platform configuration registers. This selection is then handed to e.g. the quote or seal functions.

- **TcIPolicy**

  The policy class is designed to handle authorization data for TSS objects such as keys.

The handling of errors in the TSP is based on return code. In Java, this concept is replaced by exceptions which encapsulate the errors returned from the TSS. This allows to handles TSS errors with conventional Java error handling mechanisms.

For the reason of flexibility, the TSS has been designed to return generic byte arrays instead of concrete structures. This allows to e.g. use one single function to retrieve different types of data. It is the responsibility of the developer to treat the returned data correctly. Where possible, the Java TSS Wrapper converts the generic byte blobs into the correct objects. Where this is not possible, easy to use Java representations of the equivalent C structures are available that provide developers with a simple mechanism for converting byte blobs received from lower layers into objects. This is commonly used for e.g. structures received directly from the TPM. Since this functionality is required regardless of the TCS backend, it logically is part of the TSS frontend API (see the blue boxes in Illustration 4).

- **Backend Components**

  With the split of the design into a an interface based frontend and several backends, different TCS connection types can be realized. The most obvious type is the RPC based connection. For this, a Java Native Interface (JNI) binding to the TSP is required. This JNI interface consists of a native C part that is linked to the TSP library and a Java part that implements the frontend interface. Calls the the Java level methods are routed via the JNI intermediate layer to the TSP.

  The SOAP interface for the TCS specified by the TCG is a more versatile interface to the TCS because it, in contrast to RPC, offers a well defined remote interface. This SOAP interface is planned to be supported by the Java TSS Wrapper with an own backend.

To allow simple switching from one backend to another, all backend components are created based on the factory pattern. Selecting another backend therefor is a matter of choosing another object factory. The application relying on the frontend interface does not need to be modified.

Should the need arise to implement additional communication backends, the proposed architecture is flexible enough to add those backends without problems.

2.4 Requirements and Assumptions

This section summarizes the requirements and assumptions that have been taken for the design of the Java TSS Bindings.

At the time of writing this document, the only available TSS for Linux is the TrouSerS TSS (http://trousers.sf.net). It currently only supports TSS specification 1.1 [TSS1.1] . The only implemented connection mechanism between the TSP and the TCS is the vendor specific RPC interface. There currently is no support for the SOAP interface. Therefore all experiments and prototyping done so far is limited to the 1.1 TSS specification and the JNI based backend implementation. As a consequence, this design is based on the knowledge gained from the TSS specifications and the work with the TrouSerS TSS.

It is assumed that there will be a 1.2 [TSS1.2] compliant TSS featuring a SOAP interface available within the project within a reasonable time frame.

TPM and OS driver

2.5 A native Java TSS

An alternative approach to using a 3rd party TSS with a Java wrapper on top of it is the implementation of a native Java TSS. This section is dedicated to describing the benefits of such a solution and to identify the challenges that are involved.

It has to be noted that the exploration of such a solution currently is at an early stage and not all aspects have yet been examined in detail. Therefore at the time of this writing it can not be foreseen if such an approach could supplement or even replace a wrapper for an existing TSS as described in previous sections.

A TSS is composed of two main parts, namely the Trusted Core Services (TCS) and the Trusted Service Provider (TSP). Contrary to the Wrapper approach, not only a Java front end for the TSPI and parts of the TSP have to be implemented, but also the TCS. To get an overview of the individual components that make up the TCS, Illustration 5 presents the main components and their interdependencies. The following paragraphs briefly describe the individual components shown in Illustration 5, starting at the hardware (TPM) level up to the Trusted Core Services Interface (TCSI) and the server component.

- **TPM and OS driver**
  The TPM chip forms the lowest level of the stack. TPMs are implemented by different manufacturers according to the specification of the TCG. The TSS should support both TPM specification versions: 1.1b and 1.2. Taking into account the rapid development of the IT industry, it can be assumed that hardware equipped with 1.2 TPMs will become dominant in the near future. Therefore, it seems to be acceptable to focus on the support of TPMs version 1.2.
  The OS driver, typically running in Kernel mode, is the first software component of the stack. When implementing a TSS, it can be assumed that the driver is supplied either by the TPM vendor or is already part of the operating system. Modern 1.2 TPMs no longer need a vendor specific driver but can be accessed via a TIS (TPM Interface Specification) driver.
- **Trusted Device Driver Library (TDDL)**
  The TDDL is a standardized software layer with the main purpose of providing an abstraction of the underlying OS specific TPM interface. As shown in Illustration 5, the TDDL is designed such that implementations for different systems can easily be added. For the Linux operating system, the TDDL would be implemented such that it opens the TPM device file (/dev/tpm) that is provided by the underlying driver. Microsoft Windows Vista is shipped with a generic TIS driver. TPM functionality is made available via the so called Trusted Based Services (TBS). This service interface should allow similar access to the TPM as the device file under Linux does. Consequently, for Windows Vista, the TDDL layer can be implemented using the TBS API.
- **Parameter Block Generator and TPM Structure Parser**
  The TPM offers a byte stream oriented interface. That means that all commands sent to the TPM have to be marshaled into byte streams which are then sent to the TPM. As the TPM specification defines the data exchanged with the TPM based on C structures, at first all primitive data types used (e.g. UINT32) have to be mapped to equivalent Java types. Then the C structures have to be modeled by Java classes. When sending commands to the TPM, the contents of

those class instances has to be packed into a byte stream. When receiving a response from the TPM, the byte stream has to be unpacked and decoded into Java objects.

- **Authorization Manager**

  The TPM is designed as low cost chip with a limited amount of internal resources. One of those resources that are managed by the TSS are authorization sessions. The authorization manager keeps track of the authorization sessions and if required, it swaps, evicts or re-loads TPM authorization sessions.

- **Event Manager and Event Log**

  When doing a PCR extend operation, an event log message can be specified. It is the task of the TCS to store, manage and report this information. The event log however is not limited to events that were generated via the TSS. During boot, measurements are done by the BIOS storing the log information in ACPI memory. To provide a complete event log, the TSS also has to collect this log information stored outside the TSS. Other log entries, such as those collected by IMA (Integrity Measurement Architecture) should be collected as well.

- **Key and Credential Manager, Persistent System Storage**

  Applications might need to store keys permanently. The TCS offers a system wide storage for that purpose. In this storage, a key hierarchy is defined with the Storage Root Key (SRK) as it's root. Keys stored in the persistent storage are assigned a unique identifier called UUID. This UUID can be used by applications to look up and reference keys. The key manager is responsible for storing key blobs in the persistent storage as well as for retrieving and loading keys. As part of this process, the key manager must ensure that the key chain from the SRK to the key to be loaded is established correctly.

  Credentials such as the endorsement or the platform credential are managed by the TCS. By that, it is ensured that all applications have access to these credentials using a well defined mechanism. The credentials are e.g. used as part of the CollateIdentity/ActivateIdentity cycle to create Attestation Identity Keys (AIKs).

- **TCS Context Manager**

  Resources are bound to a context representing a calling application. These application contexts are managed by the context manager.

- **TCSI API**

  This layer represents the standardized API of the TCS. The TSS specification defines this API in a C style fashion which has to be mapped to Java.

- **TCS Server Components**

  The TCS is designed to be implemented as a system service or daemon. Therefore, multiple applications are able to concurrently access the TCS. This is facilitated by the TCS server component. It accepts incoming connection requests from applications and passes them to the underlying layer. It has to ensure proper synchronization such that only one thread is allowed to enter critical sections of the TCS. The TCS server interface must be flexible enough to allow different connection mechanisms such as local calls, Java RMI or SOAP.

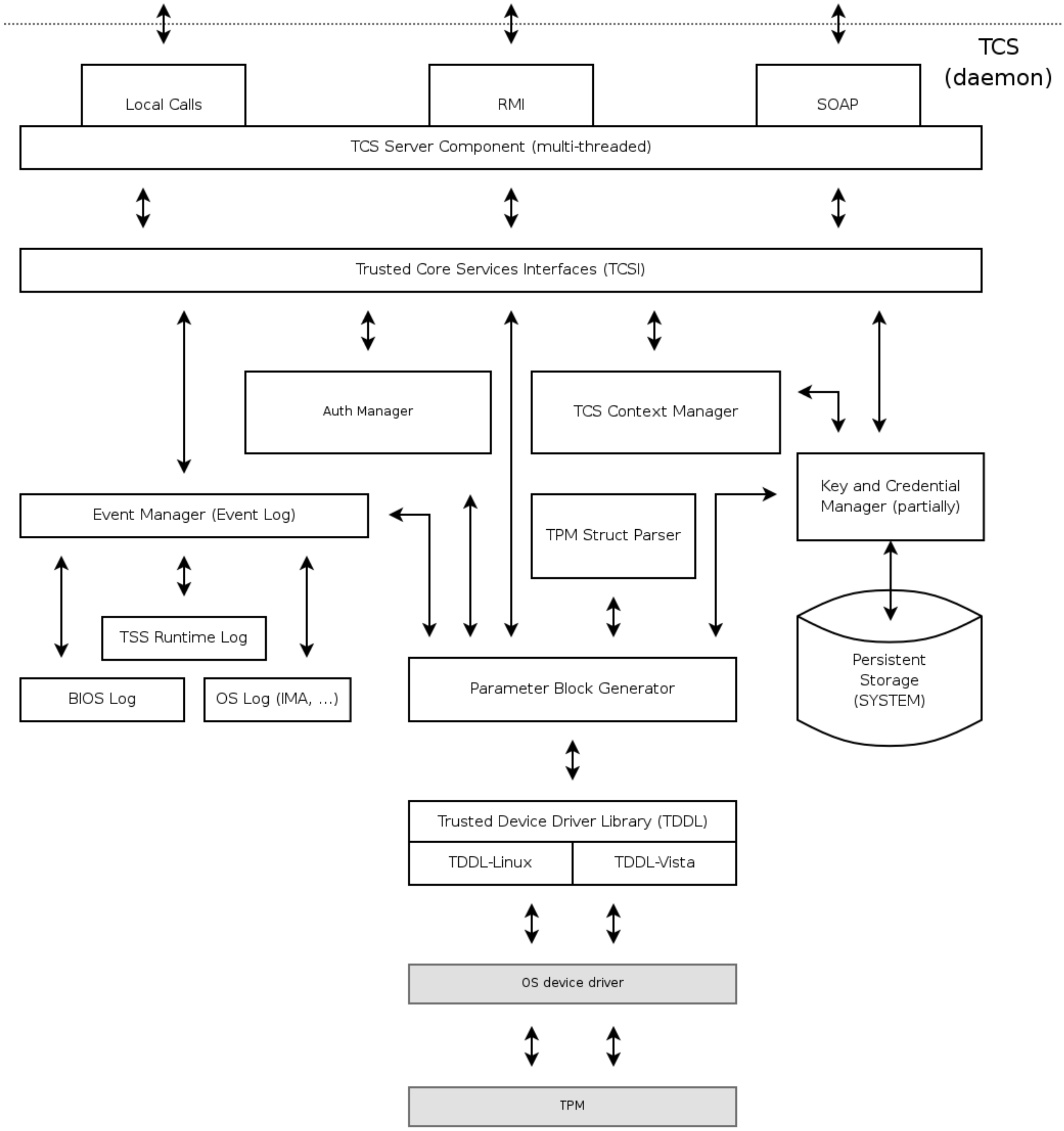

Illustration 5: Trusted Core Services Components. Request from the TSP are received via one of the communication facilities provided by the TCS server component.

After having covered the main building blocks of the TCS, Illustration 6 now provides an overview of the major building blocks of the Trusted Service Provider (TSP). The TSP typically is designed as a library that is linked to an application. Starting at the bottom of the TSP, the major components are:

- **TCS Bindings**
  Since the TCS can support different communication mechanisms, also the TSP has to offer support for different communication facilities. The TCS binding component provides an abstraction layer that allows to add communication

components later on without requiring changes of upper layers of the TSP.

- **Authorization and Validation Component**

  Access to the TPM and the TPM's resources requires proper authorization. The TPM specification defines special authorization protocols used to establish authorization for those resources. The authorization and validation component is responsible for creating and managing authorization sessions. Additionally, it validates response data received from the TPM.

- **TSP Context Manager**

  Communication sessions with the TCS are mapped to contexts. The context manager is responsible to keep track of context sessions and the management of the associated resources.

- **Key Manager and Persistent User Storage**

  TPM keys are organized in a key hierarchy where every key has a parent key in the layer above. The root of this hierarchy is the SRK. When loading a key into the TPM, the key manager has to establish the entire key chain starting at the SRK down to the key to be loaded. Users or applications can store keys in the user persistent storage. Contrary to the system persistent storage, this storage is individual for every user of the system.

- **TSPI and TSP Working Objects**

  The top level interface of the TSP is called Trusted Service Provider Interface (TSPI) and is standardized in the TSS specification. From the user's point of view, the TSPI consists of a set of “working objects” such as keys, encrypted data or hashes. These objects have been described in section 2.3.2 (Detailed Design Aspects).

- **Transport Session Component**

  Transport Sessions are a new feature introduced in TPM specification 1.2. It allows the TSS to encrypt commands and data sent to the TPM. This provides protection against attackers who intercept the data transmitted over the system's LPC bus.

Benefits and Challenges

Having a native Java TSS implementation clearly reduces the number of involved components and dependencies when accessing a TPM. Consequently this approach would result in less side-effects resulting from incompatible TSS implementations or different interpretations of the TSS specification. Moreover, a pure Java stack can easily be ported to other operating systems and platforms. This is not limited to PC type systems but also could include embedded systems equipped with a TPM.

One of the main challenges of a TSS as proposed here is the requirement to support TPMs from different vendors. While vendor specific stacks can limit themselves to supporting a few specific TPM types, a vendor-independent TSS has to support TPMs from different vendors with all their quirks.

The proposes approach of a native Java TSS will be examined further regarding feasibility and practicability.

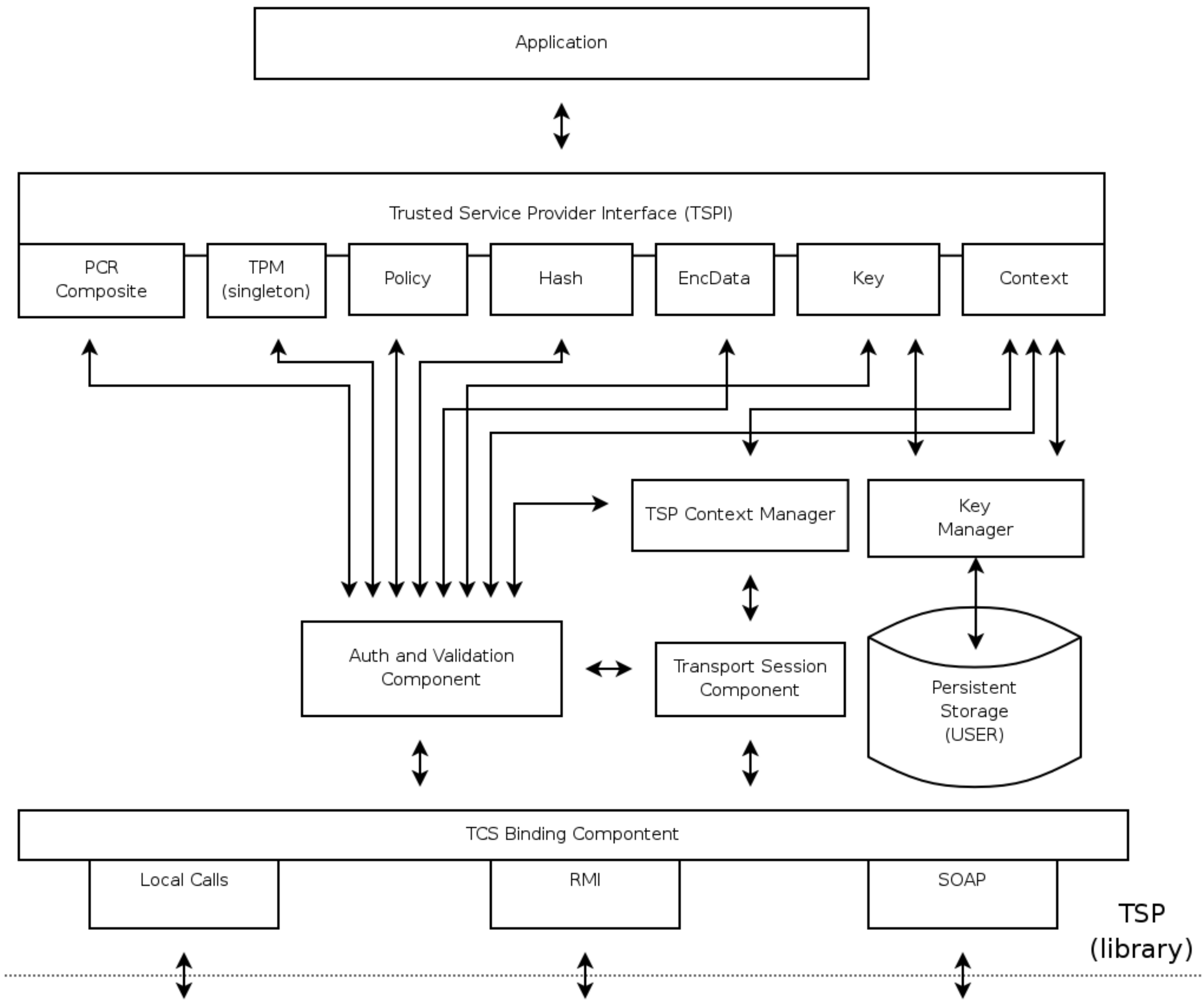

Illustration 6: Trusted Service Provider Components

3 Java Virtual Machine Modifications

This chapter summarizes the extension of the chain of trust from the operating system level to the Java virtual machine level and the Java application level. The first section describes the life-cycle of a Java program and especially the central points of interest for this project in detail: the ClassLoader and the ClassVerification Process. The next introduces the fundamentals and concepts of Java security as specified by SUN [SUNSEC]. Section 3.3 discusses the modifications to a Java virtual machine that have to be done in order to integrate basic TC technologies. The final section of this chapter presents an evaluation of existing virtual machines according to criteria like licensee model, source availability etc. Based on this evaluation, will choose a JVM that will be adapted to TC requirements.

Unless explicitly specified the following descriptions refer to version 1.4.2 of the J2SE which also is the reference for the evaluation process. Descriptions, source code snippets and implementation details also point to that JDK.

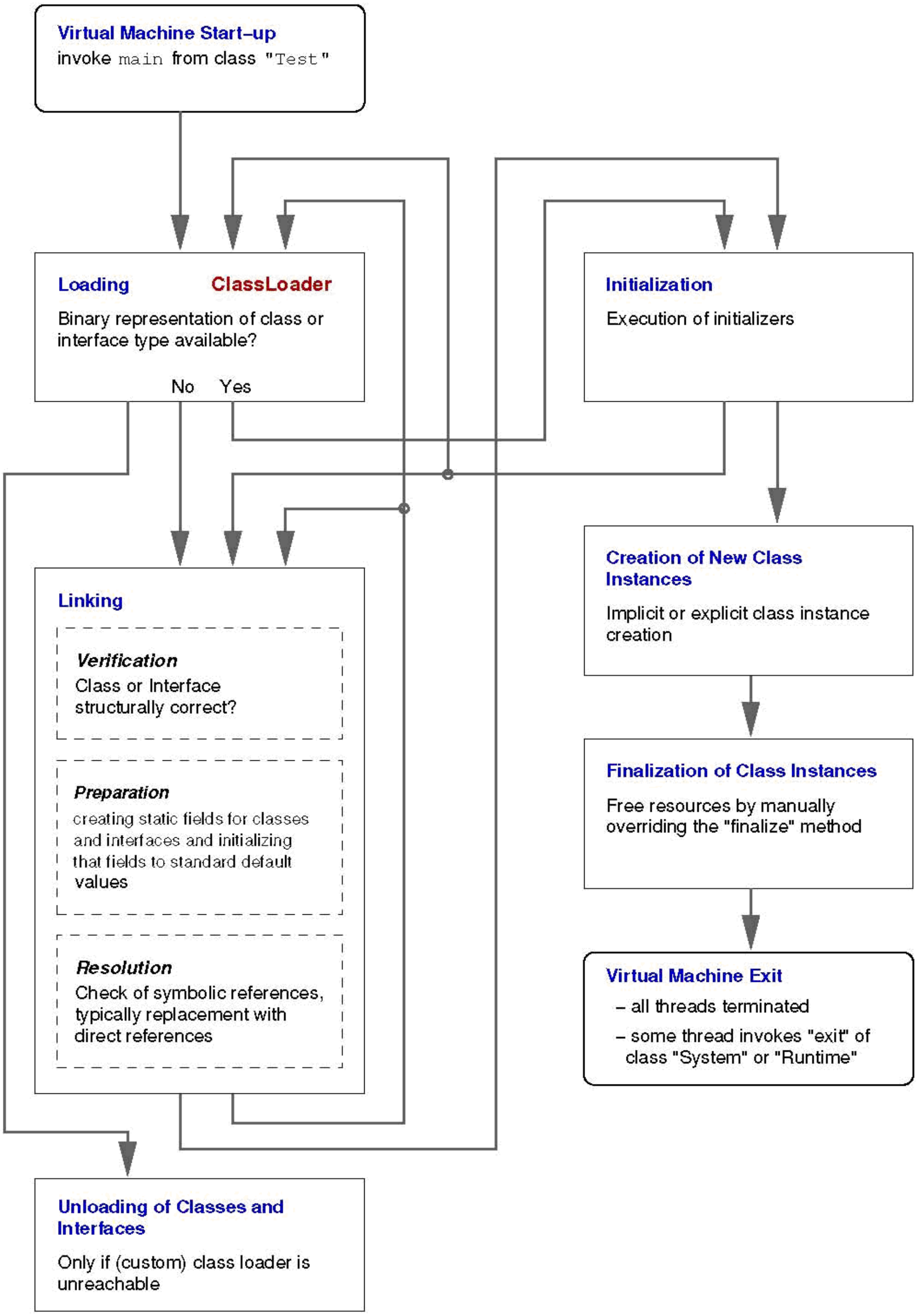

Figure 1: Life cycle of a Java program running on a J2SE Virtual Machine

3.1 Execution of Java programs

One central idea of the Java programming language is that Java compilers create code – *Java Bytecode* – which has to be executed on a Java Virtual Machine. That executable code has a special, platform-independent format which differs from other executables in a number of important ways.

Figure 1 shows the sequence of executing a Java program as described in chapter 2.17 of the Java Virtual Machine Specification -Second Edition [JVM] and chapter 12 in The Java Language Specification -2nd Ed. [JLS]. This references imply that the diagram as well as its description concerns every Java Virtual Machine that follows that specifications, especially the Virtual Machines of Sun Microsystems Inc. from the Java 2 Platform Standard Edition. It also helps identifying where it is meaningful and necessary to deviate from the basic design for fulfillment of the requirements of OpenTC.

For example, a standard Java program does not consist of a single executable file. It is usually composed of many class files, each corresponding to a single Java class. Depending on the Java Virtual Machine used , this class files normally are loaded on demand by the ClassLoader.

The program “Test” which is referenced in the diagram and also in the original chapters can be any Java program that has at least one class named Test which includes the main method. An exemplary program which fulfill these requirements in a very simple way is shown in Listing 1:

```
public class Test
{
      public static void main(String[] args)
      {
          System.out.println("Test");
      }
}
```

Listing 1: sample Java program

The following sections summarizes every step in the execution of such a program as specified by the corresponding resources as mentioned above. Additionally it shows possible points of relevance for OpenTC.

1. **Virtual Machine Start-Up**

   Initial attempt of executing the method main of class Test discovers that it is not loaded. This triggers the next step.

   OpenTC: Starting the Virtual Machine (e.g. manually from the command line or automatically) at first requires verification if the executable of the Virtual Machine itself is the right one and if it has not been manipulated. Because this point is beyond the scope of this chapter it is not further mentioned.

2. **Loading**

   In general this process tries to find the binary representation (normally the class file format) of a class or interface type. If this search is not successful as in the Test example, that representation must be created, leading to the next step: Linking. A more detailed description of the ClassLoder follows later

   OpenTC ...requires on demand verification of custom ClassLoader(s) and verification of class files before loading.

3. **Linking**

   takes a binary form of a class or an interface type and prepares it for execution. The Java programming language allows some leeway (see Resolution below), therefore the linking process is split into three parts:

   - **Verification**

     ensures that the binary representation is structurally correct. OpenTC: Manipulations on bytecode level, especially branch instructions jump to undesirable and/or incorrect instructions, can be detected here.

   - **Preparation**

     involves creating and initializing the static fields for a class or interface.

   - **Resolution**

     Symbolic references are validated and, typically, replaced by direct references so that they can be used directly. This stage is of central interest for static or lazy/late resolution.

4. **Initialization**

   This process must separate between

   - **Class**

     Execution of its static initializers and the initializers for static fields declared in it.

   - **Interface**:

     Execution of initializers for fields declared in interfaces.

   Before a class or an interface type is initialized, its direct superclass must be initialized. This may cause loading and linking again.

5. **Creation of New Class Instances**

   Implicit or explicit class instance creation identifies, calls and executes a particular constructor.

6. **Finalization of Class Instances**

   Before memory reclamation by the Garbage Collector the override-able method *finalize* is called. This provides manual memory deallocation of resources.

7. **Unloading of Classes and Interfaces** (adopted from [JLS][McCrary]

   A class or interface may be unloaded if and only if its class loader is unreachable. The bootstrap class loader is always reachable; as a result, system classes may never be unloaded.

8. **VM-Exit**

   happens if:

   - All threads that are not daemon threads terminate
   - Some thread invokes exit of class *Runtime* or *System* and the exit operation is permitted by the security manager

3.2 Java Security Model

This section gives a short introduction to the basic Java security concepts.

Java does support local applications and applications which are (partly) loaded over a network. Furthermore, Java has to provide security features to ensure that they do not do anything harmful to the local machine. Java treats trusted and untrusted code differently. The core Java libraries and locally started applications are considered as trusted by default policy. In contrary, code which is loaded over the network, is considered as untrusted. Untrusted applets run inside the so-called “sandbox”. This sandbox is restricted by the Java security model. The Java security model is comprised of three parts:

- ClassLoader
- Class Verifier and Bytecode Verifier
- Security Manager

The classloader and the verifiers are implemented in the Java virtual machine (JVM). A JVM basically runs Bytecode created by a Java compiler. The JVM specification [JVM] defines the structure of the JVM itself and the exact format of a class file. They are not covered by this document.

3.2.1 Class Loading

The Java2 ClassLoader is fully downwards compatible. Any code written for older Java versions works on the current edition of the JDK, too. Nonetheless the ClassLoader follows a completely new approach which turns some of the old methods into “deprecated” state.

The basic idea behind the improvement is to use a delegation model which can delegate a request for a class to its parent within the parent-child relationship of Virtual Machines (Figure 2). Per default a ClassLoader calls its parent before trying to load a class itself.

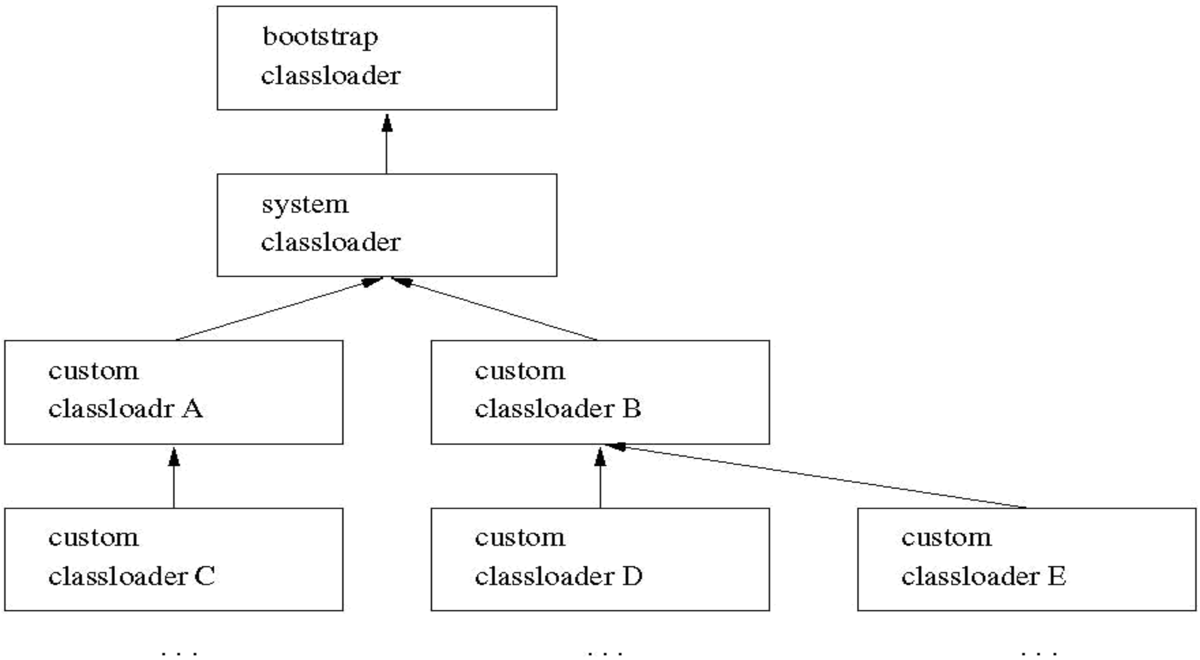

Figure 2: ClassLoader parent-child relationship

As Figure 2 shows, the delegation model from Sun differs between three Class-Loader types:

1. **bootstrap (primordial) ClassLoader**

   ... for Java core API classes. Invoking the Java compiler as follows overrides the standard location for the bootstrap Classloader: javac -bootclasspath <path>. The actual value is stored in the sun.boot.class.path system property (Note: not accessible by an applet).

2. **system (application) ClassLoader**

   ... for application specific classes. This parameter can be set via the environment-variable CLASSPATH or by setting a command-line argument of the Java compiler (javac -classpath <path>) or the Virtual Machine itself (Java -classpath <path>). The value is held in Java.class.path.

3. **custom ClassLoaders**

   . . . every application can define its own ClassLoaders which are derived from the system ClassLoader.

A full description of the new ClassLoader (including the method descriptions) is available through the Java API specification which is part of the JDK documentation.

Name	***signature***
findClass	Protected Class findClass(String)
getSystemClassLoader	public static ClassLoader getSystemClassLoader()
getParent	public final ClassLoader getParent()
defineClass	protected final Class defineClass (String name, byte [] b, int off, int len) throws ClassFormatError protected final Class defineClass (String name , byte[] b, int off, int len, ProtectionDomain protectionDomain) throws ClassFormatError

Table 1: Important methods of theJ2SE ClassLoader class

Table 1 lists the most important methods of the Class-Loader class.

The experiences with the first edition of the JDK showed that the constraint to implement the loadClass method for every custom ClassLoader is not necessary. Not only that the concrete implementation is rather complicated, many scenarios work with completely the same loading mechanisms and have no requirement to define a new one. The maintenance of multiple occurrences of this method makes it prone to errors too. So for the J2SE it was decided to provide a standard loadClass method which still can be overridden, but for most of the time there is no need for it.

Instead of overriding the mechanism for loading, the new findClass method is introduced. The delegation idea implies that it is encouraged to override this method in every ClassLoader derivative. This strategy simplifies the life for a custom ClassLoader developer remarkably.

Listing 2 shows the concrete realization of the new loadClass method in J2SDK 1.4.2-12 (original javadoc comments are omitted) which is the starting point for every class loading process. Looking at the signature it is important that loadClass is defined as synchronized which makes it impossible to execute this method more than once simultaneously (this affects multi-threading). The body starts by checking if the class not already is loaded (line 5). If not, the delegation process starts. Within the try block (lines 8-12) the ClassLoader calls its parents until there are no more which means that the parental calls moved up through the whole ClassLoader parent-child tree. There it calls the bootstrap findClass method (line 11). Note, that this method – “findBootstrapClass0” - is the only implementation of findClass that always exists and really searches for the class. It throws an exception if the search is not successful. After that all invoked loadClass methods get their chance for a successful finding of the class (line 16, within the catch-block) or otherwise throw an exception by their own. Note: This findClass methods only exist if they have been overridden by the respective child-implementations of the ClassLoader. If the search was successful the class may be linked (lines 19-21) by calling resolveClass, depending on the parameter *resolve.*

3.2.2 Class Verifier and Bytecode Verifier

Clearly, Sun's Java Compiler produces valid bytecode in class files. The JVM has no chance of checking whether a class file has been compiled by Sun's Java Compiler or by another compiler. Therefore, the class file has to be checked against several problems such as

- Operand stack overflows or underflows
- Invalid local variables operations
- Invalid JVM instructions and arguments

The JVM Specification defines four passes for the verifier. Pass 1 and pass 2 belong to the class verifier which checks the class statically and pass 3 and 4 belongs to the bytecode verifier.

- **Pass 1 (during loading)**

  The class verifier checks the basic format and the integrity of the class file. It checks for the appropriate header (magic number and version number) and it checks that all data has the correct length. Moreover, the class file must not contain extra bytes at the end and must not be truncated.

- **Pass 2 (during binding)**

  This pass is also done by the class verifier. It checks basic Java concepts that can be verified without looking at the source code. These concepts are e.g.:

  - Each class (except java.lang.Object) has a superclass
  - Final classes must not be subclassed
  - Final methods must not be overridden
  - Field and method references have valid names

  The verifier does not check in this pass that the referenced methods and classes really exist.

- **Pass 3 (during linking)**

  The Bytecode verifier checks the methods of a class with a data-flow analysis. This process is rather complex, the basic checks are:

  - Variables are initialized before reading
  - Methods are called with the correct number and types of arguments
  - Fields hold only objects of appropriate type

  The JVM Specification defines an exact algorithm for the bytecode verifier which is not covered in this document.

- **Pass 4 (during runtime)**

  The checks in this pass can also be done in pass 3. This pass resolves class and methods references and checks whether the classes exist or not. It also verifies that the caller has access to the reference.

3.2.3 Security Manager

The security manager handles the access control. If an application wants to take control of a resource it has to ask the security manager and the security manager grants or denies access to the resource. The exact working principle for the application is as follows:

1. Check whether the security manager is enabled or not
2. If the security manager is enabled ask for granting access to the resource
3. The security manager silently grants access or throws a SecurityException in the case of denial
4. If the security manager is disabled, the application gets access.

There can only be one security manager at the same time for an application. It is not possible to create more than one security manager and it is not possible to disable a running instance of a security manager. For local applications, the security manager is disabled by default. It can be enabled manually at start time of the application. For remote applications, the security manager is enabled e.g. by the Appletclassloader.

The controls are implemented by the access controller. The security manager calls the appropriate method of the access controller for:

- Installation of a new classloader
- File Access (read/write/delete)
- Access to threads (start/stop)
- Sockets (accept/open a new connection)

The end-user can customize the controls of the security manager by editing simple text files called policy files. Within these files, the user can grant access to the resources for all applications or defined applications. The granularity of permissions was introduced in Java 2. For older versions of Java, an application had either “all rights” or “no rights”.

3.3 Integration of Trusted Computing in a Java Virtual Machine

This section is about continuing the chain of trust from the operation system level up to the JVM level and the Java application level by the integration of TC techniques in a JVM. The two TC features which will be used are *measuring* and *sealing*. There should be a version of the modified JVM with “measuring only” features without any sealing features.

3.3.1 Measuring

Measurement of data means to hash the data and then update the appropriate platform configuration registers (PCRs).

From the point of view of the operating system, a Java virtual machine is an application like any other application. Therefore, the measurement of the JVM is not different from the measurement of an application.

Classes are loaded dynamically by the classloader. Therefore, the enhancements of the JVM regarding Trusted Computing take place in the classloader. Classes are only unloaded if and only if their defining classloader is reclaimed by the garbage collector. Thus, the core Java classes are never unloaded because the primordial classloader can not be destroyed [JLS]. Therefore, class unloading and reloading is not featured in this document. For the first iteration, the measurement (building the hash value) of the single classes or the jar-package of a Java application will be implemented in a self-defined classloader and the application is loaded through this classloader. For the next Iteration of integrating TC features into a JVM, the measurements and (un-)sealing processes are integrated into the primordial classloader and other classloaders. Due to the fact that classloaders are Java code, it is possible to use the Java TSS API for the TC features. A Java application does not only comprise of Java classes. Configuration files and static data (e.g. pictures) are parts of Java applications. Consequently, these data files have to be also measured and sealed.

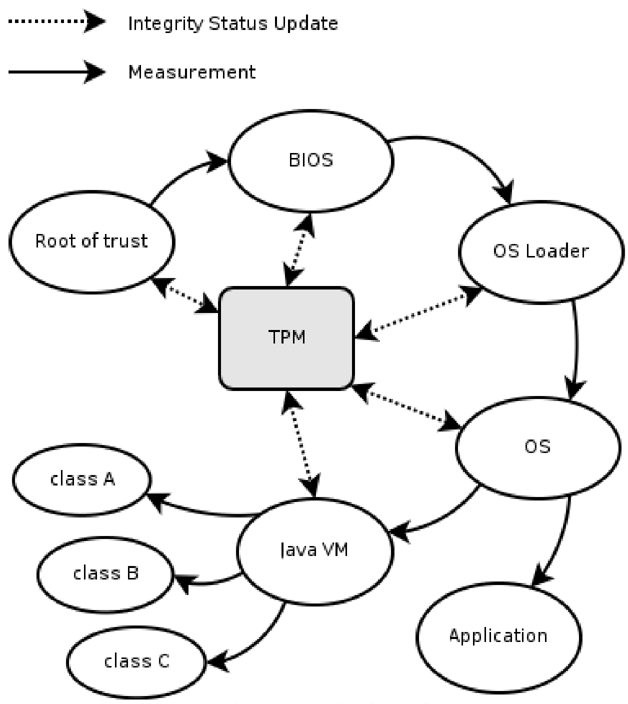

Illustration 7: Chain of Trust

Native libraries of an application are loaded via the methods System.load(libraryname) or System.loadLibrary(libraryname) depending on the fact, that the library is included in the library path. Therefore, native libraries should be measured as well.

3.3.2 Sealing

Sealing is the process of encrypting data with regards to specific TPM metrics i.e. a chosen set of values of the PCRs. Unsealing the data is only possible if and only if the TPM metrics chosen for the sealing process are exactly the same as for the unsealing process. The sealing key is a non-migratable TPM key. Sealing Java classes has to be done before measuring them, otherwise that would break the unsealing process. Due to the fact, that the order of classes to be loaded is not deterministic, the jar-package of the Java application should be sealed instead of the single classes. Furthermore, the jar-package is not sealed directly, because this would require too much time. It is encrypted with a symmetric key and this key is sealed in the common way. At the end of the lifetime of the Java application, its (unsealed) jar-package is deleted from memory.

An application scenario for sealing a Java program could be, that a system administrator installs and seals a Java program for the non-administrators of the computer. This means, normal users are only able to unseal and run the application, but can not modify parts of them or install a new version of it.

3.3.3 The Property-based approach

The main problem of the traditional measuring/sealing approach is that there are different versions of classes due to updates and patches of an application. Therefore, a database has to store all different versions of a class and all hashes of these versions or otherwise, this would break the remote attestation. An idea to solve the problem would be not to measure the classes themselves (the binaries), but to measure the properties of the application or properties of the virtual machines. This idea of measuring the properties of a program for remote attestation is known as "Semantic Remote Attestation" or "Property-based Attestation" [PBA] . The same idea holds for the sealing process. "Property-based Sealing" [SDMTC] seals data objects according to a set of properties rather than according to PCR values within traditional sealing.

A possible set of properties could be:

- status of the security manager - Is the security manager enabled?
- file access rights - Is it possible for the application to read/write/delete files?
- process management rights - Is it possible for the application to start or stop threads?
- Network access - Is it possible for the application to accept or open network connections?

4 Evaluation of existing Java Virtual Machines

To develop a secure Java Virtual Machine in the terms of OpenTC there are basically two options to follow: develop a new one, or base the development on an existing one. Since development of a full VM is clearly out of scope – at least in terms of ressources available – we needed to find a Virtual Machine fitting several requirements. Figure 3 shows the three-step scheme which has been used to accomplish this task.

4.1 Search

The search for appropriate Java Virtual Machines began by using the well known online resources. This first step resulted in a long list of candidate VMSs that is presented in section 3.3. VMs, that did not fulfill the most basic criteria, are listed in section 3.3.2. Also, VM-Projects that were apparently "dead" could be sorted out immediately (see section 3.3.1). The result of searching and afterwards applying that rules is shown in "Selected Candidates".

4.1.1 Requirements

In the first stage there were only a few reasons to eliminate Java Virtual Machines:

Wrong platform: This means that the Virtual Machine is made for special purposes. For example: Virtual Machines which are made only for Microsoft Windows compatible machines or Apple Computers or Virtual Machines for embedded systems are not in the focus of this project.

License: If the license is not compatible to the OpenTC specifications and cannot be changed to a compatible one.

Development unfinished: If the Virtual Machine is in a buggy state and/or insecure or it is a “just for fun” project then it has no perspective in this project.

Old Virtual Machine: Some Virtual Machines stopped development in past for different reasons. Selected Virtual Machines should at least cover the Java 1.4.2 rule set.

4.1.2 Selected Candidates

Name	Homepage	Organization
CACAO	www.cacaojvm.org	Technical University of Vienna (www.tuwien.ac.at)
IKVM	Jeroen Frijters	www.ikvm.net (jfrijters@users.sourceforge.net)
IntelORP	orp.sourceforge.net	Intel Corp (http://intel.com/research/)
JamVM	jamvm.sourceforge.net	Robert Lougher (rob@lougher.demon.co.uk)
JanosVM	www.cs.utah.edu/flux/janos/janosvm.	University of Utah (http://www.cs.utah.edu/)
Java HotSpotVM	Java.sun.com/j2se/1.4.2/docs/guide	Sun Microsystems
JikesRVM	jikesrvm.sourceforge.net	IBM Corp.
Kaffe	www.kaffe.org	Free Software Community Project
kissme	kissme.sourceforge.net	Sourceforge project
SableVM	sablevm.org	Private Initiative (Contact: egagnon@sablevm.org)

Table 2: Resulting JavaVirtual Machines after selection stage (alphabetical order)

4.2 Evaluation

Based on the list of accepted Virtual Machines from the searching stage we will examine the remaining candidates in detail.

In the following section criteria for this examination are specified (see section 2.1). Then, for repeatability of evaluation, a testing environment is pinpointed in section 2.2. Finally each of the Java Virtual Machines will be looked at and analyzed and the results and measurements will be noted. This phase is currently in progress, the final evaluation results will be available in Q1 2007.

4.2.1 Evaluation criteria

The finally selected Java Virtual Machines have to meet different criteria which also

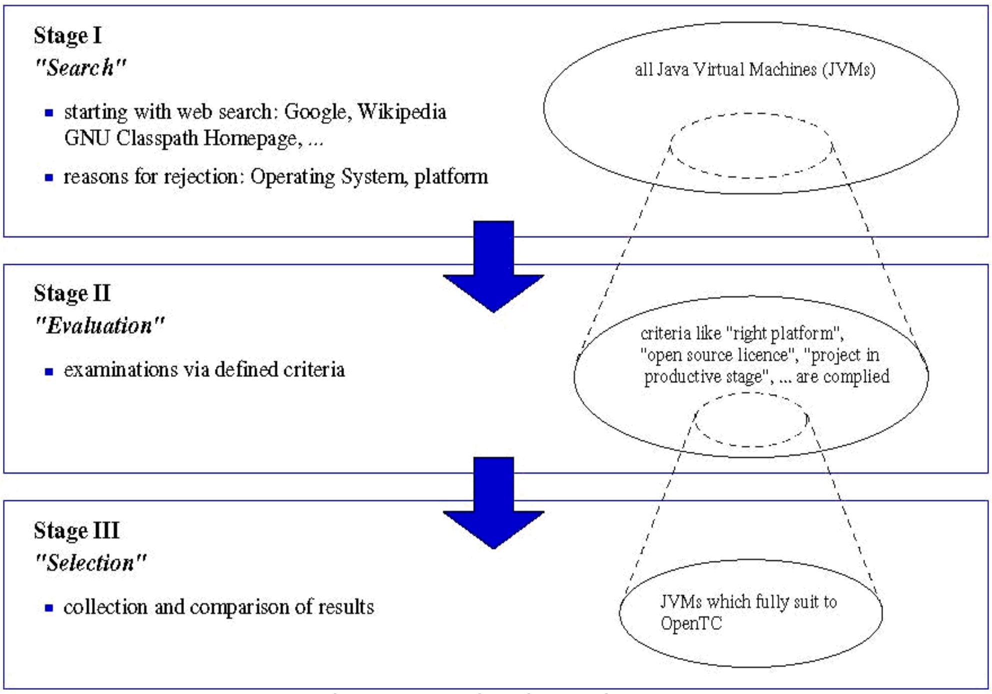

Figure 3: Selection scheme

have different impact on the decision. So these criteria are split into two sections:

Main Criteria ... are crucial points for the selection and have a direct impact on the decision.

- License (Cost)
- Sourcecode Availability
- Quality
- Project Status
- Project Activity
- Performance

Additional Information ... Nice to have. Cover facts and information about the Virtual Machine which does not fit into the first section.

- Operating System Compatibility
- Installation Process
- Distribution
- Miscellaneous

4.2.1.1 License (Cost)

The planned work in OpenTC will require changes to major parts of the finally selected

Virtual Machines (ClassLoader and the ClassVerification process) and the right to distribute the resulting (modified) Java Virtual Machines under the open source licenses. Thus the original Virtual Machines must also have been published under such licenses.

There exist a lot of different OSS licenses. Many of them are only slightly different to others and it is really hard to know all of them in general and nearly impossible each of them in detail. To accelerate the process and to establish a clear line of decision this evaluation accepts the same licenses as the Sourceforge project (www.sourceforge.net) does.

4.2.1.2 Sourcecode Availability

An important prerequisite for the modification of a selected Java Virtual Machine is the “physical” existence and fully granted access to all pieces of source code which are needed to build that special Virtual Machine.

This means:

- Full information about concrete location(s) where to get the code (e.g. via FTP (File Transfer Protocol), CVS(Concurrent Versions System), ...)
- Granted access to that location(s).
- Complete set of tools, libraries, additional resources and information which is needed to build the concrete Virtual Machine.

If one Virtual Machine in the evaluation process does not support this point in all details, the consequence is elimination from the further selection.

4.2.1.3 Quality

The basic parts of Java Virtual Machines are well defined and can easily be compared among each other. To make this comparison more expressive the general term “quality” is split into different, more detailed definitions which are of greater benefit for this evaluation.

As already mentioned before (see on the previous page), the most important parts of the Java Virtual Machine for this project are the ClassLoader and the verification part of the linking process.

This is also important for quality issues. Because of the exact knowledge where modifications will need take place this can be used for precise evaluation. That means that criteria like source code quality, coding conventions, . . . can be based on a limited set of source code files instead of checking the whole Virtual Machine.

Source code quality (implementation)

Measures how good the programmer of a Virtual Machine utilized the programming language(s). Obfuscated code cannot be accepted!

- Is it easy to read the source code?
- Does the programming cover (all) the problems in a direct and simple way?
- Is there a clear and structured way of programming visible?

Programming Language

Points of interest are:

- Which languages are used by the Virtual Machine? There are no known restrictions selecting a programming language to implement a Java Virtual Machine. Nevertheless the interface to the operating system most of the time is written in a language used for programming the operating system itself (C, C++).
- Is the Virtual Machine compatible to the TSS-API (Trusted Software Stack -API) or to jTSS (Java Trusted Software Stack)? The project uses the interfaces specified by OpenTC and offered in the the TSS-API (written in C) which has been made Java compatible using the jTSS wrapper. So the selected Java Virtual Machine should be written (at least the critical parts) in C or Java.

Coding Convention

Code review, refactoring and upgrading are made easier by continuous usage of Coding Conventions. Nonetheless, a coding convention rule-set should be short and concise. Questions:

- Is there any coding convention and is it declared in a clear way?
- If one exists, is it the only one and is it valid for all pieces of code?

Documentation

At least the crucial points of the Virtual Machine should be well documented. This includes:

- Description of usage, restrictions, errors, known problems.
- General description of functionality.
- Source code documentation (methods, parameters, . . .)

Again the main focus lies on **class loading** and **verification**.

Bug Management

Error tracking, short response times to reported problems and transparent error information politics are examples for good work and may turn out to be important.

Security

Since the VM will be part of a trusted system, quality of the software development is important for the level of security. While this may be difficult to evaluate, apparent lack of parameter handling, possibility of buffer overruns and other weaknesses will result in negative evaluation.

Completeness

The complexity of the Java programming language is defined in the Java Language Specification [JLS]. A Virtual Machine may implement just part of that set. For us a full implementation of Java 1.4.2 is desired.

4.2.1.4 Project Status

The state of the project informs about how far advanced the development process of an examined Virtual Machine is. Typically this information is available from the Virtual Machine website in different forms like "*to do lists*", *error reports*, ... In addition, feedback by users on the actual and also past releases as well as reputation and distribution of the tested Virtual Machine will be verified..

Examples for project status ratings are experimental, buggy, alpha, beta, finished project, stable, productive or similar expressions.

As an alternative approach the project status can be taken as an approximation from different measurements like the state of documentation, source code quality, error-proneness, ...

It is recommended to select a Java Virtual Machine which is in a finished or almost finished state.

4.2.1.5 Project Activity

The project activity criterion focuses on the following points:

Number of project members

The more the better. This guarantees reachability, more critical work, less delay on questions, errors, . . .

Release intervals

For example: if there is only one release every two years, the activity is low. But even though at first sight it seems to be very clear, this measurement should be rated carefully. Of course the number of releases can be higher with more project workers. But it needs to be checked if all releases are necessary and meaningful.

Speed of changes and updates -reaction time on errors

This point can be important if some functionality is missing or a new bug is detected.

Each investigated Java Virtual Machine is classified into one of four categories: extraordinary, good, normal, below requirements.

Because the measurement of project activity is always a little vague there will be an explanation on each of the ratings, especially on the extreme ones.

4.2.1.6 Performance

Performance indicates the speed of Java code execution on a given Java Virtual Machine.

It is clear that performance depends on the programming language the Virtual Machine is implemented in. Targeting a special niche may also influence performance. For example: A Java Virtual Machine including many additional helper functions for debugging purposes is probably much slower than without that methods. But focusing execution speed at all cost can involve that “additional” methods, for instance used for byte code verification (and as a consequence for security purposes), are not executed any more. In this case the speed gain could be bad for the goals of this project.

Since performance currently is not a top priority, and since getting objective performance data itself is a difficult task, we decided to skip this evaluation for the time being. One benchmark [SHUDO] comparing only some of the selected Java Virtual Machines was found and therefore consulted.

4.2.1.7 Operating System Compatibility

This is another nice to have feature. Since Linux is the target operating system for OPEN_TC, availability for Linux is a must. If A VM supports other operating systems as well, this is noted.

4.2.1.8 Installation Process

While it is obviously comfortable to have a nice install tool, this is not necessary and does not influence the decision pro or against a Virtual Machine.

Points which are noted:

- Documentation
- Tools
- Dependency of Libraries.

4.2.1.9 Distribution

When there is any information about the available distributions this will be placed under this point. Of special interest is a connection to security related projects, and scientific or educational usage.

4.2.1.10 Miscellaneous

Additional features, information or properties are collected here. Also special remarks which do not match to any other criterion are noted here.

4.2.2 Testing Environment

For detailed examination of each Java Virtual Machine they will be downloaded in the latest available release. This download must include at least a stable source release (beta or better). Any additional resources which are necessary for running the Virtual Machine or something like helpful tools, documents etc. are downloaded, too.

Operating System	Debian Linux (Etch) Kernel version 2.6.9 build with gcc version 3.4.2 a
Computer System	IBM Thinkpad A31p, Intel Mobile Pentium 4-M 2.0GHz, 1GB RAM, 100GB HDD GNU

Classpath Version installed: 0.91-3 latest: 0.92 (since 09 August 2006)

```java
protected synchronized Class loadClass(String name, boolean resolve)
  throws ClassNotFoundException
{
// First, check if the class has already been loaded
  Class c = findLoadedClass(name);
  if (c == null) {
    try {
      if (parent != null) {
        c = parent.loadClass(name, false);
      } else {
        c = findBootstrapClass0(name);
      }
    } catch (ClassNotFoundException e) {
    // If still not found, then invoke findClass in order
    // to find the class.
      c = findClass(name);
    }
  }
  if (resolve) {
    resolveClass(c);
  }
  return c;
}
```

Listing 2: loadClass method in J2SDK 1.4.2-12

5 Complete list of Virtual Machines

Remark: the descriptions are based on or copied from the website of the respective project.

Name	Source	License	Short Description
Aegis	The Aegis Project	LGPL	Lightweight, secure
CACO	TU Vienna	GPL	
GCJ	FSF	GPL	Java compiler out of the GCC (GNU Compiler Collection). Different approach for running Java code.
IKVM.NET	Jeroen Frijters	zlib/libpng	Java for Mono and Microsoft .NET
Open Runtime Platform	Intel Corp.	Intel Open Source License	research platform for academic use
JamVM	Robert Lougher	GPL	small, speed improved

Name	Source	License	Short Description
JanosVM	University Utah	GPL	concentrates on safe asynchronous multi-threading
JAOS	ETH Zurich	own license	
JC	Archie Cobbs	LGPL	concentrates on fast execution via code analysis
Jikes RVM	IBM Corp. CPL	GPL	commonly used in research
Jnode	Ewout Prangsma	LGPL	complete Java operating system
Jupiter	University of Toronto	GPL	academic project, concentrates on scalability (cluster infrastructure)
Kaffe	Free Software Community Project	GPL	widely spread, well established
kissme	SourceForge project	GPL	mostly written in C, persistent storage
LaTTe	Seoul National University	similar to BSD	research project, concentrates on fast JIT (Just In Time) compilation on RISC machines
LeJOS	Sourceforge	LGPL	very small (< 32kb), for LEGO Mindstorms RCX
SableVM	Free software	LGPL	small, fast, efficient, easy portable
teasme	Sourceforge	GPL	runs in an adapted Linux kernel

5.1 Apparently Dead Projects

Name	Source	License	Short Description
Chockcino	N/A	Announced	for RISC OS and ARMLinux
ElectricalFire	Mozilla	MPL	performance oriented
IBM Jalapeño	IBM Research	Non free	For Java Servers, written in

Name	Source	License	Short Description
			Java
KaffePC	N/A	N/A	Virtual Machine based on Kaffee

5.2 Not applicable VMs

The following VMs have been excluded because they seem not to be suitable for the target platforms used in OpenTC.

Name	Source	Short Description
CEE-J	Skelmir	Fast Virtual Machine for the embedded market.
Superwaba	Superwaba	Virtual Machine for PDA
Intent Java Technology Edition		includes a Java VM using to be used on low end embedded devices
IPJV		Embedded virtual machine, designed for J2ME
Jeode	Insignia	Java virtual machine environment tailored for embedded devices
PERC		clean-room JVM expressly created for demanding embedded systems
pVM		full function Java-compliant Virtual Machine (32K in byte size, and even smaller for JavaCardVM) which runs without an operating system
savaJe		32-bit multi-tasking, multi-threading operating system with integrated 1.3 J2SE (virtual machine and runtime library)
simpleRTJ		simple Real-Time-Java: for the small embedded and consumer devices is a clean room implementation of the Java Virtual Machine that has been specifically designed to run on devices with the small amount of system memory (from as low as 48KB)

Name	Source	Short Description
TINITiny InterNet Interface		a combination of a small but powerful chipset and a Java programmable runtime environment. The chipset provides processing, control, device-level communication and networking capabilities
TinyVM		open source Java based replacement firmware for the Lego Mindstorms RCX microcontroller. The RCX is a programmable brick that comes with Lego's Robotics Invention System

5.3 Summarized examination results

The following list contains projects that have been excluded from further investigation. The reasons for excluding them are given.

Remark: the descriptions are based on or copied from the website of the respective project.

5.3.1 Aegis

Criteria	***Results***
Homepage	http://aegisvm.sourceforge.net/
Description	Open source Virtual Machine with an effort to make a lightweight and secure solution available. A special feature is the Pluggable Verification Module Facility which allows developers dynamic linking of Java specific pluggable verification modules or other byte code analyzers.
Reasons for rejection	• no current information (last entry in mail-list from may 2003) • uses outdated version of classpath libraries

5.3.2 Chockcino

Criteria	***Results***
Homepage	http://chocky.mine.nu/Java/, http://www.chocky.org/Java/
Description	No current information available!

Criteria	Results
Reasons for rejection	• no current information • dead links (no downloads available, no tests applicable) • Java 1.1 • concentrates on RISC • no free license available

5.3.3 ElectricalFire

Criteria	Results
Homepage	http://www.mozilla.org/projects/ef/
Description	Designed for performance. Uses just in time compilation techniques for acceleration. Internal project team disbanded due to a strategic shift in January 1998. Made publicly available on mozilla.org in January 1999 and now runs under the open source Netscape Public License which seems to be the same as the Mozilla Public License(on page 61).Works on x86 Linux and Windows 95/98/NT. Several processor architectures are supported.
Reasons for rejection	• supports only up to JDK 1.2 • latest official “news” are dated to 1999 • still under construction (even for JDK 1.2)

5.3.4 GCJ

Criteria	Results
Homepage	http://gcc.gnu.org/Java/index.html
Description	GCJ(GNU Compiler for the Java Programming Language) itself is a compiler for the Java programming language. It follows a slightly different approach fur running Java applications. Java source code has to be compiled with GCJ and afterwards it has to be linked with the GCJ

Criteria	Results
	runtime (libgcj) which provides the remaining functionality of a Java Virtual Machine (ClassLoader, garbage collector, ...). Applets are not fully supported by now! But even though the implementation of Java.applet seems to be nearly complete, the GCJ lacks a functional AWT. The compiler is under GPL, but other components (e.g. the runtime libraries) are under various free licenses (copyrights held by individuals).
Reasons for rejection	• no full support for Java Applets • GCJ supports only most of the JDK 1.1 language features • the compound of GCJ and libgcj are not exactly a JavaVirtual Machine • GCC is a big project and it probably takes a lot of configuration and maintenance beside the parts that would be important for this project.

5.3.5 IBM Jalapeño

Criteria	Results
Homepage	http://www.research.ibm.com/jalapeno/
Description	Written in Java and designed for Java servers, this non free project was promoted in October 2001 to the open source Jikes ResearchVirtual Machine (RVM) (http://jikesrvm.sourceforge.net/) which also gets evaluated in this project
Reasons for rejection	• non free • moved to a new project (JikesRVM) • no online resources available

5.3.6 IVKM

Criteria	*Results*
Homepage	http://www.ikvm.net/
Description	Interesting project because .NET itself s based on an own Virtual Machine. The Java Virtual Machine and Java class libraries are implemented in .NET
Reasons for rejection	• basic approach via Mono (http://www.go-mono.org/) too complicated for this project (doubles the effort) • security (additional layer additional Virtual Machine)

5.3.7 JAOS

Criteria	*Results*
Homepage	http://www.oberon.ethz.ch/jaos/
Description	Embedded as a case study into the Oberon project(http://www. oberon.ethz.ch/) and in this case designed for the Bluebottle System. JAOS (Java on Active Object System) is an interesting academical project.
Reasons for rejection	• running on AOS(Active Object System), which is limited in hardware support (running a TPM successfully is questionable) • own, BSD like license http://www.oberon.ethz.ch/jaos/license.txt • implementation of the operating system and the Virtual Machine in Active Oberon programming language • project activity is low since 2003 (works with GNU Classpath 0.06, current: 0.92)

5.3.8 Japhar

Criteria	*Results*
Homepage	http://www.hungry.com/old-

Criteria	*Results*
	hungry/products/japhar/
Description	no current information available.
Reasons for rejection	• current project homepage offline and/or pirated(www.japhar.org) • available information is old and outdated (1998) • no sources are ready for download even on the old page (ftp-server seems to be offline)

5.3.9 JC

Criteria	*Results*
Homepage	http://jcvm.sourceforge.net/
Description	another very interesting approach. JC uses the Soot bytecode optimization framework (http://www.sable.mcgill.ca/soot/), especially its bytecode analysis part, to convert class files into C source code and then compiles it with GCC. JC concentrates on code preview techniques to speed up execution time of the binaries. It seems to be much slower if the time measurement starts at class loading. This could be an interesting starting point for future investigations. For now the approach seems to be a little bit too complicated (because of the usage of code analysis techniques and GCC).
Reasons for rejection	• concentrated on fast binaries • complicated approach (at this state too many security implications to worry about)

5.3.10 Jnode

Criteria	*Results*
Homepage	http://www.jnode.org/

Criteria	Results
Description	Jnode is not only a Java Virtual Machine, it is a full operating system written almost completely in Java. The goal of such a system is to get higher performance because executed code runs directly on the operating system instead of passing through additional software layers. Disadvantages which may occur are: less compatibility to hardware and a higher security risk because, once more, the execution of applications runs direct on the operating system core. On the other hand, in context with OpenTC this could be an advantage because there are less layers to certificate. Summary: an interesting project in an advanced state (e.g. referencing the Jnode homepage, it even has beaten Suns Virtual Machines in performance, hardware compatibility is increasing and it is one of the few which fully supports the J2SDK 5.0).
Reasons for rejection	• Doesn't fit to OpenTC

5.3.11 Jupiter

Criteria	Results
Homepage	http://www.eecg.toronto.edu/jupiter/
Description	Jupiter is a modular and extensible research project which just supports basic Java code execution (Java interpreter with multithreading capabilities). It is designed to be highly scalable for work in a cluster infrastructure.
Reasons for rejection	• no support for ClassLoaders written in Java • no JIT compiler • no bytecode verifier • supports JDK 1.3.1

5.3.12 KaffePC

Criteria	Results
Homepage	http://ns.distribution.co.jp/freeware/Java/kaffepc/en/
Description	No current information available
Reasons for rejection	• apparently dead

5.3.13 LaTTe

Criteria	Results
Homepage	http://latte.snu.ac.kr/
Description	academic approach to develop a competitive JIT on a RISC machine.
Reasons for rejection	• limited to Solaris 2.5+ on UltraSPARCs (both are trademarks of Sun Microsystems Inc.) • targets to RISC machines • supports only up to Java SDK 1.1 • incomplete class library • own license (similar to the BSD-license)

5.3.14 leJOS

Criteria	Results
Homepage	http://lejos.sourceforge.net/
Description	LeJOS is a Virtual Machine which replaces the firmware on the LEGO Mindstorm (http://mindstorms.lego.com/) RCX (micro-controller -for details see http://graphics.stanford.edu/~kekoa/rcx/) which makes it possible to run Java on it. The main feature is its size which is small enough to take place on the 32kb ROM(Read Only Memory)module. This may be an interesting project for future initiatives in embedded JavaVirtual Machine developments.

Criteria	Results
Reasons for rejection	• developed for LEGO Mindstorms RCX • little documentation (especially on limitations)

5.3.15 teaseme

Criteria	Results
Homepage	http://teaseme.sourceforge.net/
Description	Written in C and based on the kissme Virtual Machine and a very outdated version of Classpath. Builds a kernel module. The project seems to be (nearly) stopped. No information about tests with actual kernels. The available version seems to be buggy and in connection with the fact that it is realized as a kernel module this seems to be not very faithful.
Reasons for rejection	• very low documentation level • outdated (last actions in 2001, last version update in 2000)

6 Prototype Application

To demonstrate our efforts and achievements in modifying the Virtual Machine we are going to develop a prototype application. In order to use synergy effects our prototype application will be the Proxy implementation we developed for the PET demonstrator. The respective documents can be found in the WP5 deliverable.

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D03d.4 Java VM for TCP implementations

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Report (see p 84/85 Annex 1 - Nature)

Deliverable reference number	IST-027635/D03d.4/RC|1.0
Deliverable title	Java VM for TCP implementations
WP contributing to the deliverable	WP03d
Due date	Oct 2007 M24
Actual submission date	

Responsible Organisation	IAIK
Authors	IAIK (Tobias Vejda)
Abstract	This document describes Java Virtual Machine enhancements to support Trusted Computing implementations.
Keywords	Trusted Computing, Java, Measurement Architecture

Dissemination level	Confidential
Revision	RC|1.0

Instrument	IP	**Start date of the project**	1st November 2005
Thematic Priority	IST	**Duration**	42 months

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1 Introduction

This deliverable deals with the design of the integration of Trusted Computing into the Java programming language environment. The Java programming environment has seen a broad adoption ranging from large-scale business applications hosted in dedicated data centers to resource constrained environments as found in mobile phones or Personal Digital Assistants (PDAs). Java programs are not compiled to native machine code but to a special form of intermediate code, called byte code. This byte code is then executed by a virtual machine (VM) called the Java VM. The main focus of this document lies on the Java VM itself.

NOTE: This document describes a detailed design and implementation of the amendments to the Java VM described in OpenTC deliverable D03d.2.

1.1 Scope and Outline of this Document

The focus of the work described in this document lies on extending the chain of trust as defined by the Trusted Computing Group (TGC) to Java applications. To this end, we implemented a integrity measurement architecture for the Java VM. The term measurement refers to the TCG definition which defines measurement as hashing the contents of security relevant files. We further address the problem of attesting to properties of selected security features of a virtual machine environment.

The outline of this document is as follows: Section 2 gives an overview over the basic concepts of the Java VM which are needed throughout this document. Section 3 describes the design of the integration of the measurement architecture into the Java VM. Section 4 outlines our implementation. Section 5 presents some results of this work. Section 6 addresses open issues and gives an outlook to future work.

1.2 Related Work

We give an overview of related work in this area in this section.

The concept of *Property-Based Attestation* (PBA) [SAD04] proposes an alternative to the attestation mechanisms specified by the TCG (henceforth called *binary attestation)*. A *Trusted Third Party* (TTP) translates the actual system configuration into a set of properties and issues certificates for those properties. During the attestation process a (remote) verifier can decide whether or not the platform security properties meet the requirements of the respective use case. In literature, using TTPs for certification of properties is called *delegation*. This scenario avoids several (undesired) drawbacks of the attestation process defined by the TCG. At first, the specific system configuration is hidden from the verifier. In a real-world setting, management of all possible configurations is a complex task. Further, presenting the actual system configuration to a verifier is not desirable from a privacy perspective. The final argument against TCG binary attestation is that it allows possible attackers to gain information about a system which could then be exploited to actually mount an attack.

Another proposal deals with a generic attestation framework for virtual machine monitors [JAN06]. The authors describe an architecture used for attestation and verification. For this purpose, they define generalized attestation as a projection of the *Stored Measurement Log* (SML) file using a mapping. For binary attestation, the mapping is the identity function. For property attestation, the mapping can be defined to attest to high-level properties. However, the paper does not contain a concrete instantiation example of the mapping for attesting to properties.

Alternatively, *Semantic Remote Attestation* (SRA) [HAL04] uses language-based techniques to attest high level properties of an application. The proposal is based on the *Java Virtual Machine* (JVM) environment which is attested by binary attestation itself. The JVM can enforce a security policy on the running code based on data flow control and taint[1] propagation mechanisms. Hence, this approach is a hybrid approach between binary attestation and attesting to properties.

The Policy-Reduced Integrity Measurement Architecture (PRIMA) [JAE06] performs measurements for code and data that belongs to or communicates with *trusted subjects*. The underlying principle is the *Biba integrity model* which separates high and low integrity processes (or subjects) and requires that the information flow to a process is at its integrity level or higher. The model is extended to enhance run-time integrity measurement through identification of trusted subjects and through filtering of the information flow in the system. Those two goals are achieved with the help of *Security Enhanced Linux* (SELinux) and its *Mandatory Access Control* (MAC) policy. The rationale behind this approach is that not all processes on a platform contribute to the trust status of an application. Hence, the measurement includes only the application itself and all code that is incorporated through information flows. Those are restricted to the subjects trusted by a remote verifier.

The idea of a form of generalized attestation has also been envisioned in a position paper about *Trusted Virtual Domains* (TVDs) [LIN05] in the setting of secure distributed services. The authors identify several classes of properties that are potentially useful for attestation which we discuss in the next sections. Whereas some of the property classes aim at different levels of abstraction, the following list shows properties addressable by a JVM:

- Confinement (isolation, confidentiality) – refers to the secrecy of code/data and its isolation from other entities (code/data).
- Immutability – refers to read-only enforcement of data.
- Integrity – refers to the integrity status of data in accordance with the Biba integrity model.
- Secure I/O primitives – refers to available secure communication and/or storage facilities.
- Identity – refers to identity properties of components of a platform.

1 Data is referred to as *tainted*, if it originates from an untrusted source (e.g. a network source).

2 Review of Required Java Virtual Machine Functionality

We briefly review functionality of the JVM in this section to give an introduction to the concepts important to the design and implementation described in the following sections of this document.

2.1 Dynamic Class Loading

Dynamic class loading is a feature of the Java VM specification. Classes are loaded during run-time from any location pointed to by the class path. Such a location can also be a network location. The class loaders form a tree structure to enable a delegation model. A class loader can delegate the loading of classes to a parent class loader and, if the loading fails, try to locate and load classes itself. The root of the tree is the so-called bootstrap (or primordial) class loader. The loaded classes are assigned to so-called *protection domains* which prevent leakage of information between trusted code and application-specific code.

2.2 Java Native Interface

The Java Native Interface (JNI) allows the application designer to use programming languages such as C/C++ or assembly to interact with Java applications [JNI07]. The interface is two-way, that is the native code can also access Java objects, i.e. create, inspect and update them, call Java methods, catch and throw exceptions, load classes and obtain class information. Examples for native libraries are standard I/O, file I/O and sound capabilities which are shipped with the VM.

2.3 Security Architecture

The security architecture of the Java language encompasses several mechanisms of which the access control mechanism is the most interesting for our purposes.

2.3.1 Permissions

The security model for the Java VM allows a fine grained policy based on permissions. A permission is abstracted by a Permission object and there exist several subclasses reflecting the different parts of the Java VM such as SecurityPermission, RuntimePermission, FilePermission, NetPermission, SocketPermission, etc. The enforcement of permissions is done via the security manager class. On a security relevant call, the class library invokes the security manager. Hence, the main focus of the security enforcement mechanisms lies on class level.

2.3.2 Principals

The Java security architecture assigns permissions to so-called protection domains. A protection domain encompasses a code-base (i.e. a location of the class path), a principal, and a set of permissions. The principal is identified by a certificate chain.

2.3.3 Access Control Mechanism

The algorithm that enforces access control is called stack inspection, that is, the decision whether a method is allowed to access a resource is based on the call stack. The algorithm searches each stack frame starting from top to bottom (hence starting from the most recently called method) and tests whether the method has the appropriate permissions to access the resource. Each stack frame is mapped to a protection domain through the class the method (that actually is represented by the frame) belongs to. Each protection domain has an assigned set of permissions which can be easily checked.

If the algorithm encounters a frame marked as privileged it terminates and grants access. This privileged frame is marked through calling the doPrivileged method of the access controller which, so to say, enables the privileges of a class. The point here is that some method may have privileges that caller methods may not have, like accessing a system resource. An example where this proves to be useful is a caching mechanism for a network connection. An application itself does not need to have permissions for file access but the system class performing the caching needs such permissions.

2.4 Serviceability in HotSpot

The JVM specification and HotSpot as a concrete implementation provide several interfaces for serviceability [OJDK07]. Those interfaces allow the operation of the VM being observed by another Java process. In the case of a trusted VM, interfaces that allow the alteration of data are of special interest. This is due to the fact that the classes are loaded during runtime which does not cover any changes made to the executable in memory. A list of those interfaces is shown in Table 1. Mostly these interfaces deal with inspection only; an exception poses the *Java Virtual Machine Tool Interface* (JVMTI).

Table 1: Serviceability Interfaces in HotSpot

Interface	***Description***
Serviceability Agent	Sun private component developed to assist debugging of HotSpot; exposes Java objects as well as HotSpot data structures
Performance Counters	Exposed for performance evaluation; through shared memory
Java Virtual Machine Tool Interface	Reference implementation of the Platform Profiling Architecture; inspection and modification of the VM's state
Monitoring and Management Interface	Sun private API to inspect HotSpot
Dynamic Attach	Allows to launch external process in the VM that can be used to start a JVMTI agent
Dtrace	Probing interface for Solaris
PStack	Allows to print stack traces of all threads; Solaris specific

2.4.1 Java Virtual Machine Tool Interface

The JVMTI is designed as an interface for debugging and monitoring tools. It is accessible through so-called agents which are C/C++ libraries and which run in the same process as the JVM. It allows to inspect the state of the VM as well as control the execution of applications. For example, an agent can start or stop threads, inspect memory regions (stack, heap) and access classes of running Java applications. For the latter, the interface also provides functionality to alter class data. An agent is started through the command line parameters “-agentlib” and “-agentpath” referring to its location and gets initialized in an early state of the VM.

Byte-code Instrumentation

Byte-code instrumentation is the ability to alter the byte codes which form a class of an application running in a VM. In general, three approaches do exist: static, load time and dynamic instrumentation. Whereas static instrumentation refers to replacement of class files on disk, the two latter approaches allow a library to alter byte-codes during runtime. As a measurement architecture usually measures the class files loaded from disk, the measurements may not reflect the code running in the VM.

There are several implementations showing the power of this approach, for instance, the BCEL library from the Apache project, ASM from the ObjectWeb Consortium, and BIT from the University of Colorado. An attack on the trusted VM could be replacing a reference to a class by a reference to a subclass performing possibly harmful operations. Hence, in the context of a trusted VM, the JVMTI is a security problem and should be turned off. Note that the JVMTI is a possibility to implement Trusted Computing functionality for the JVM as well, as shown in the semantic remote attestation approach [HAL04], for example. Furthermore, if the underlying operating system measures shared libraries at load-time, an attack could be detected.

3 Design of the Measurement Architecture

We will discuss the differences in the design choices in this section. We base our design considerations on the OpenJDK implementation from Sun. In general, for a virtual machine environment like Java, we have to distinguish two possible points of measurement: the HotSpot VM which is coded in C/C++ and the Java class library which is implemented in Java. The design has to take care of those two layers.

3.1 Integrity Measurement Process

The *Integrity Measurement Process* has several aspects we need to discuss. For the integrity status of an application running in a Java VM class files and native libraries are important. For class files, we distinguish the Java class library (as shipped with a distribution), external libraries, and application-specific code.

To cover the first aspect, we extended the class loading mechanism of the JVM. Before the actual byte code is instantiated in the JVM, the files are hashed and extended into a PCR (using the *PCR extend* call of a TPM). A special case for class loading is the reflection API of the Java language. Using qualified names, the application designer can dynamically load classes. For trusted class loading, this has no impact as those classes are loaded through the usual class loading mechanism and are thus measured as well.

JAR-files contain a collection of class files and their measurement offers the possibility to reduce the PCR extend calls to the TPM. Our experiments with the measurement architecture show that measurement of single class files can significantly affect the performance of class loading if there is a large number of class files used by an application. If JAR-files are measured, the measurement overhead can be reduced to a minimum. As JAR-files are the usual way to distribute Java applications, this approach is the most practical one. Note that this also introduces a significant time gap between the time of measurement and time of execution that is larger compared to the one during loading and measurement of classes: The Java VM implements a lazy class loading algorithm. That is, the loading of classes is delayed as long as possible until the code is actually needed. Opening JAR-files on the other hand is done when the VM searches for classes and several JAR-files may be opened before the class is found.

The second aspect, native libraries, are dynamically loaded during runtime and a measurement architecture has to take care of those libraries. Furthermore, as the library code directly runs in the Java VM, it has full access to its resources. There exist two points at which we can perform this measurement: either in the operating system, or in the class loading mechanism of the VM.

Addressing the first choice, IBM designed an *Integrity Measurement Architecture* (IMA) on an Linux environment [SAI04]. In their design, they intercept a set of system calls where files (executables, shared libraries, ...) are loaded and IMA measures it to a PCR. Hence, as the VM loads the libraries dynamically, IMA takes care of the measurement and we can omit further treatment of this issue. The second choice, measuring native libraries in the Java VM, can only deal with the library directly inferred by the application (or system code). However, loading a shared library on a system can cause several other libraries to be loaded by the operating system which the Java VM cannot control or measure.

The integrity measurement process as implemented in the trusted Java VM is depicted in Figure 1. The implementation also allows to run the Java VM with known classes only. A verification function compares the measurement of a class to a *Reference Integrity Measurement* (RIM). If the flag secureBoot is disabled, the verification is not carried out and the corresponding PCR is always extended.

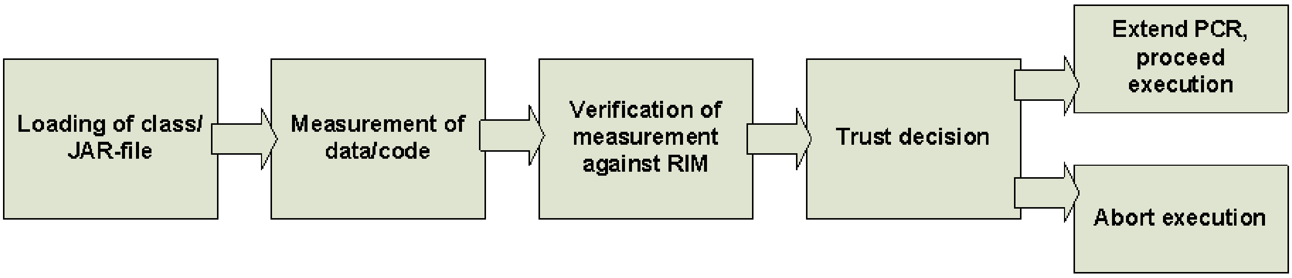

Figure 1: Secure boot process. If secure boot is disabled, verification is not carried out (the trust decision is always positive).

Table 2 shows the methods where we placed our measurement hooks. It summarizes both hooks inside the HotSpot VM and hooks inside the Java class library.

Table 2: Important classes/methods where we placed hooks for the integrity service provider facility.

Class (Method)	***Place***	***Description***
ClassFileParser.parseClassFile()	VM	Hook where all classes are parsed
ClassLoader.loadLibrary()	Class lib	Hook where native libraries are loaded
URLClassPath$FileLoader.getResource()	Class lib	Method where class files are loaded from an URL (which refers to a directory)
URLClassPath$JarLoader.getJarFile()	Class lib	Method where JAR-files are loaded from an URL
PolicyFile.addGrantEntry()	Class lib	Hook where policy entries are added to the security policy

3.2 Usage of Platform Configuration Registers

An important point in the measurement architecture is the usage model for the *Platform Configuration Registers* (PCRs). Each application that is run inside a virtual machine is extended into a single PCR. Furthermore, if two virtual machines run on a single PC, they both will extend their measurements into a single PCR. Again thinking further, any virtual machine that is started on a PC (and then terminated at some point in time) extends this single PCR. So, for instance, if the user starts an application, terminates it again, and then starts it a second time, this application is measured twice into the same register. A PCR in the case of the Java VM hence represents a whole cycle of work on a PC during its uptime.

Compared to the Integrity Measurement Architecture (IMA) proposed in [SAI04], the operating system has more power to manage measurements. Obviously, the operating system never gets unloaded and hence the data structures introduced in IMA can hold links to already measured files. If a file is opened a second time, IMA hashes it and compares this hash to the hash in its data structures. If the hashes are the same, everything is fine and no PCR is extended. If the hashes differ, the PCR is extended with the new hash value. This allows IMA to only report a file twice if it is really necessary and detect changes (malicious or not) to files. This mechanism cannot be adapted to the VM measurement architecture for the obvious reason that, if the VM terminates, the data structures get reset and the measurement protocol is no longer available.

Those facts impose several restrictions on the architecture. At first, there need to be separate registers for extending the virtual machine itself, and the applications that run on this virtual machine. Otherwise it will not be possible to seal any Java application to this VM configuration. If we suppose the operating system takes care of the measurement of the VM, it can also detect changes in the executable and core libraries of the VM as outlined in the IMA approach. Furthermore, as files are usually not measured twice, the value in the PCR for the VM represents a unique value to which applications can be sealed to. For the case of several VM instances running on a system, either the operating system measures the base libraries of the Java VM (including the VM itself) and prevents several instances to be measured into the same PCR, or those instances run in separate compartments utilizing virtual TPMs.

3.3 Property-based Approach

The measurement of plain-text configuration files is, in some circumstances, too cumbersome. If we look at the Java security policy as an example, it is a defined structure, but still allows numerous possibilities to achieve the same policy. Trivial examples are empty lines, additional whitespace, different sequence of properties, comments, etc. As there exists no template or canonicalization for such files as is common practice for XML documents, for instance, hashing the file provides no robust means to get a unique value for a distinct configuration. The solution for binary attestation would be to include a human-readable form of the configuration file in the SML, hence leaving the task of determining the trustworthiness of the configuration to the remote verifier (or to an attestation proxy as defined in some of the property-based approaches, e.g. [SAD04]).

In addition to the the measurement approach, we chose to evaluate properties of the access control mechanism of the Java VM, especially:

- Activation of the security manager
- Permissions that affect the runtime security of the trusted VM

3.3.1 Activation of the Security Manager

The activation of the security manager is done via the command line argument -Djava.security.manager. Either the default implementation can be used or a custom class, given as an argument to this property. The security manager is enabled in the Launcher class. As the security manager performs checks inevitable for a security relevant implementation, we chose to activate it by default. This has several impacts on running applications.

At first, the default policy for a Java applications is quite restrictive if a security manager is enabled. For example, the default policy allows access only to a few system properties and no disk access, etc. The policy shipped with a TC enabled VM should provide a trade-off between flexibility and giving to much permissions to applications, which may result in security holes.

The security policy of the JVM is represented in the PolicyFile class. As the implementation allows different locations of policy files, the VM has to maintain a central point to collect and store the different permissions. This is also the point where we place our hooks.

3.3.2 Mapping Permissions to Properties

Whereas the measurement of executable files is straightforward to implement, it is different with certain system properties. As with property-based attestation, the system configuration is translated into a set of properties that the configuration provides. The properties discussed in this section cannot directly be measured. For example, it does not make sense to measure the security manager class as the Java executable can be invoked without activating the security manager[2].

We chose to map the in-place security policy of the Java VM into a (small) set of properties that can be evaluated by run-time checking[3]. The list of properties is as follows:

- Security manager: This property tells an attestor whether the security manager is installed and whether an application has the rights to 1) create and set an own security manager 2) to modify the system policy. The affected security permissions are “createSecurityManager”, “setSecurityManager”, “setPolicy”, “getPolicy”, and “createPolicy”. For reflection, applications shall not be able to read private members of a class which is enforced by “suppressAccessChecks”.
- Runtime: This property tells an attestor whether certain runtime security properties are in place. For instance, it reflects whether an application is allowed to stop or modify threads or thread groups. It affects the security permissions “modifyThread”, “modifyThreadGroup”, “stopThread”. Furthermore, it reflects the ability to start executables using Runtime.exex() which is essentially a restriction to execute files. Note that an application is always allowed to stop its own thread (to be able to stop the VM).
- Class loading: Reflects the ability to load/set custom class loaders. The permissions that affect this property are “createClassLoader”, “getClassLoader”, “setContextClassLoader”, “enableContextClassLoaderOverride”.
- Native code execution: This property tells an attestor whether the application has the ability to load native libraries. It affects the security permission “loadLibrary”.
- File access: This property reflects whether an application has access to the file

2 There is actually a subtlety with this fact. The fact that the the SML includes the measurement of the security manager (through measurement of the SecurityManager class) does not imply the security manager is running. An attacker could, for instance, simply instantiate the security manager and chose not activate it. The instantiation would suffice for the class to be measured during loading.

3 One could think of these properties as a set of “super”-permissions.

system or not.

- Network access: This property reflects whether an application has access to the network or not.

4 Implementation

We provide a component-based description of our implementation in this section. The architecture is depicted in Figure 2. The main component is called *Integrity Service Provider* (ISP). It consists of a measurement agent, a verification agent, a storage manager, and a reporting agent.

As discussed in Section 3, we view at the Java VM having two distinct layers: the HotSpot VM and the Java class library. An implementation of the ISP is located in both locations. Note that the integrity measurements in the bootstrap class-loader (in the HotSpot VM) can be omitted if the operating system measures the class library. Nevertheless, the architecture provided in this section is implemented on both layers allowing different trade-offs between performance and flexibility.

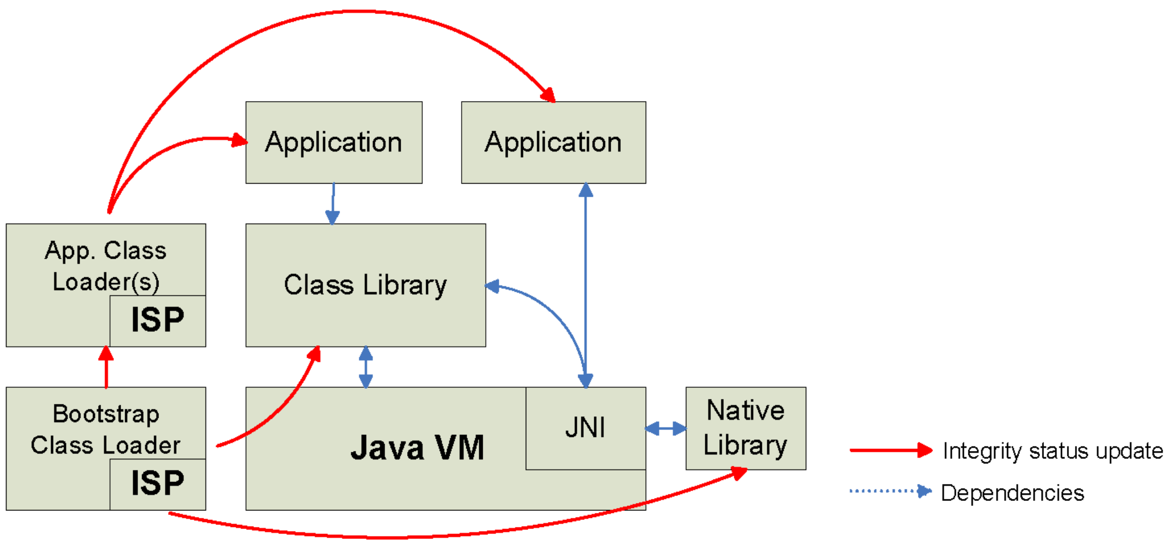

Figure 2: Architecture of the VM including the Integrity Service Provider.

4.1 Integrity Service Provider

The ISP manages the integrity measurement architecture discussed in Section 3. It provides an interface for the functionality necessary to measure and report the integrity status of the Java VM. The dependencies of the ISP are shown in Figure 3. The ISP is enabled via the command-line (see Section 4.7) and the policyEnforcement flag resembles this setting.

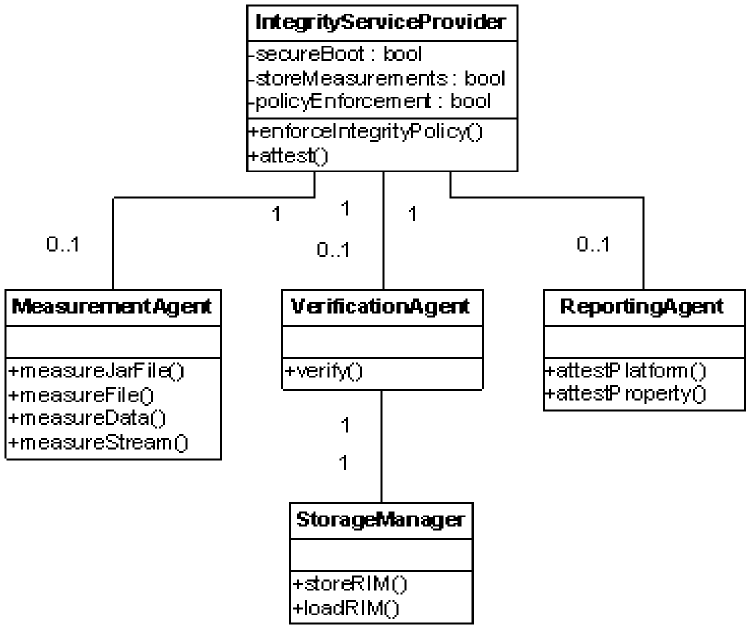

Figure 3: Components of the integrity measurement architecture for the Java VM.

The ISP class also covers the functionality needed for a secure boot of the Java VM. Note that the term “secure boot” here refers to the Java VM only. That is, we do not make any statements on the platform (and its boot process) apart from the Java VM. In contrast, this modus allows to run the VM with known classes only. On occurrence of a class that is not previously known – resp. the measurement differs from a known-good value RIM –, the VM is terminated with an error message.

For reasons of simplicity, the measurement architecture allows to store the measurements of the classes loaded during runtime. Hence, in a first run, the RIMs for an application can be created and distributed. This is reflected by the storeMeasurements flag in the ISP.

4.2 Measurement Agent

The Measurement Agent (MA) offers an interface to measure data that is crucial to the state of the platform. For the Java VM this would be class-, JAR-files, and native libraries. The implementation calculates a hash of the full file.

An exception for measurement pose dynamically created classes. The reflection mechanism allows to create so-called method-accessor classes at run-time depending on the user input. As this cannot be foreseen, those special classes are excluded from measurement.

For the implementation in the HotSpot VM, two possible measurement agents exist: one that directly measures a class file into a PCR and the other one that caches the measurements inside the Java VM before transferring the data to the TPM. We called the latter approach lazy measurement.

4.3 Verification Agent

The Verification Agent (VA) takes over the task of verifying the measurements taken by the MA against known-good values. It offers a simple interface verify(identifier, hash) to accomplish this task. Loading the corresponding hash values from disk is abstracted by the storage manager.

4.4 Storage Manager

The storage manager class abstracts operations necessary to load and store RIMs from a location. In general, the storage of RIMs has to be protected from tampering as the secure boot mechanism relies on that. There exist two possibilities to do this.

- Storage inside a shielded location
- Signed RIM (i.e. use certificates)

On a general purpose computer, the number of RIMs may become large which possibly introduces storage problems. If the Java VM running on a device using only a restricted number of applications the storage inside a shielded location is possible. The more practical solution would be to use cryptographic means to ensure the integrity and authenticity of RIMs which then can be kept on any type of storage.

The infrastructure working group of the TCG works on interoperability of the TC components across different platforms [IWG07]. It has specified an *Integrity Manifest* (IM) which is an XML document specifying the components of a platform. It is not restricted to software components but also identifies hardware components. It incorporates, above other, information about the vendor, the exact version and patch level of a component, the digest method, and the digest itself. The IM has to be cryptographically signed to identify the creator of which not all may be trusted and to maintain integrity itself. Further schemata deal with the reporting of integrity information.

Other specifications, such as the mobile working group's specification also contain secure boot capabilities. It relies on RIM certificates and verification keys. To implement these capabilities, amendments to the TPM functionality are made.

The current implementation does not support cryptographic securing of RIMs. However, the implementation supports extensions concerning RIMs. For instance, the storage manager could be amended to support the infrastructure specified in [IWG07].

4.5 Reporting Agent

The reporting agent takes over the task to report measurements to a remote verifier. It is not implemented in the current version of the ISP.

4.6 Property Collector

The property collector is the entity that updates system properties as defined in Section 3.3.2.

4.6.1 PolicyPropertyCollector

The abstraction of system policies in Java is done by the PolicyFile class (a singleton instance of class Policy). Each time an entry in any of various configuration files (which can be configured in the file java.security) is added to the system policy, the class PolicyPropertyCollector evaluates the permission entries and updates the system properties as defined in Section 3.3.2. The current implementation is for testing purposes of this approach only and is not published at the moment.

4.7 Additional System Properties

We introduced four additional system properties in our implementation which allow to configure the ISP during start-up of the Java VM. The properties to enable the ISP via the command line are:

- iaik.tc.enable: Enables the ISP and allows two modes. Either the ISP in the VM itself (via -Diaik.tc.enable=vm) or in the Java class libraries (via -Diaik.tc.enable=Java) are activated.
- iaik.tc.debug: Shows debug information about the files that are measured and what actions are taken.
- iaik.tc.secureboot: Runs the VM with known classes only. This parameter also needs the storage directory of the measurements specified by iaik.tc.store.
- iaik.tc.store: Specifies the storage directory of the reference measurements (via -Diaik.tc.store=<directory>). If the parameter iaik.tc.secureboot is not given, the ISP uses this directory as a target directory to store the measurements.

5 Results

This section outlines results we have obtained from our implementation. The class-loading process is an integral part of the VM where performance is an important issue. We evaluated several approaches and give the results in this section. The results are preliminary and will be refined in the future to give more exact figures for different application sizes etc.

The numbers have been obtained through the jvmstat [PERF07] utility provided by Sun. This graphical tool makes use of the JVMTI interface and depicts the time used for various tasks of the VM, for example, garbage collection, class loading, etc. It can be attached to a running Java VM process. The numbers were achieved on a Pentium 4 Dual Core running at 3 GHz. The numbers depict maximum values as execution time varies slightly between different invocations. However, it should give an idea on the performance impact of integrity measurement on class loading.

The test application we used was the Metalworks demo from the OpenJDK build which needs about 1500 classes. The reference value is 250 ms for the class loading as it is implemented in OpenJDK. The software (SW) TPM we used was a TPM emulator, the hardware (HW) TPM was a TPM by STMicroelectronics:

- For measuring each class separately using
  - HW TPM: > 30 sec
  - SW TPM: 1.5 sec
  - Lazy evaluation (caching in VM): 300 ms
- For measuring the application classes only using
  - HW TPM: 900 ms
  - SW TPM: 300 ms

In general, the granularity of the approach highly affects the performance of the VM. The numbers show that, for hardware TPMs, the numbers of invocations of integrity status updates should be kept as low as possible. This favors the approach to measure JAR-files instead of single class files. Hence, class file measurement should only be performed if the class is not part of a JAR-file. Another possibility is to use a measurement agent that caches the measurements inside the Java VM and delays the integrity status update to the time of attestation.

6 Outlook

The implementation of the integrity measurement architecture for trusted class loading in Java VMs is dependent on the class loading process. However, this process is about to change in further versions of the VM as outlined in Java™ Module System [SUN07a] and Improved Modularity Support in the Java™ Programming Language [SUN07b]. Whereas both specifications aim at redesigning the JAR-file deployment option for Java using a modularized approach, they require a redesign of the class loading and launching process of the Java VM.

A fact that supports integrity measurements as defined by binary attestation is that the new Java module will incorporate version information which is currently not supported. As binary attestation relies on information about the version and patch level of a software component, this information could easily be provided.

The property-based approach as described in this document is an ad-hoc mapping of permissions to properties. However, the careful selection of security properties is inevitable and the proposed selection gives only a starting point. It is also not defined yet how these properties can be integrated with the instantiation of an attestation protocol. Furthermore, as the stack inspection mechanism has been criticized by several researchers (see [PIS07] for a recent survey in this field), the security of the access control model may not be given.

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8 List of Abbreviations

IMA	Integrity Measurement Architecture
PCR	Platform Configuration Register
VM	Virtual Machine
XML	eXtensible Markup Language
JVMTI	Java Virtual Machine Tool Interface
API	Application Programming Interface
MA	Measurement Agent
VA	Verification Agent
ISP	Integrity Service Provider
SM	Storage Manager
TTP	Trusted Third Party
PBA	Property-Based Attestation
SRA	Semantic Remote Attestation
RIM	Reference Integrity Measurement

Integrating Trusted Computing into the Java Programming Language

D03.d5: Java API and Library Implementation

Project number	IST-027635
Project acronym	Open_TC
Project title	Open Trusted Computing
Deliverable type	Internal Specification

Responsible Organisation	IAIK
Authors	Ronald Tögl, Michael E. Steurer

Dissemination level	Internal Deliverable
Revision	1

Revision Sheet

ReleaseNo	Date	Revision Description
1	30.04.2008	Initial release

Table of Contents

1 Introduction

This deliverable reports an approach to integrate Trusted Computing into the Java programming language environment.

Java is a platform with integrated security features and therefore well suited for Trusted Computing (TC) software. However, the current releases of Java do not provide support for the TC functionality which is available in todays hardware platforms equipped with a Trusted Platform Module (TPM).

This document introduces the **jTSS API** with two different library implementations. The API provides TPM access within the Java environment and allows developers to make use of the concepts described by the Trusted Computing Group (TCG).

The presented software bases on the Java2 Standard Edition (J2SE) Desktop-PC system architecture and is available for download from [trustedJ] under an open source license.

1.1 About this Document

This deliverable D03.d6 presents the Java API and two implementations of it developed in the Open_TC project.

Chapter 2 two provides an introduction to the API and background information on the library design. It is the revised and final version of deliverable D04.d3/Chapter 2 which was originally authored by Kurt Dietrich, Peter Lipp, Martin Pirker, and Thomas Winkler.

In Chapters 3 and 4 we present the manual and installation guidelines for the jTSS binary deliverables. The original authors are Thomas Winkler, Ronald Tögl, Martin Pirker and Michael E. Steurer.

Finally, Chapter 5 includes the complete, detailed API definition of the TSP layer and may serve as reference manual. It is originally authored by Thomas Winkler and Ronald Tögl. Where appropriate it cites standard documents of the TCG.

This overall document was revised and edited by Ronald Tögl and Michael E. Steurer.

2 TSS Architectures and Design

The Trusted Computing Group (TCG) specifies the Trusted Platform Module (TPM) and the accompanying software infrastructure called TCG Software Stack (TSS). This system service defines interfaces to applications written in the C language. The goal of this work is to make the TSS available to Java developers in a consistent and object oriented way.

We introduce the ***jTSS API*** that targets at application developers and provide two implementations: ***jTSS*** and ***jTSS Wrapper.***

The Trusted Computing Group (TCG) designed the TSS as the default mechanism for applications to interact with the TPM. In addition to forwarding application requests to the TPM the TSS provides a number of other services such as concurrent TPM access or a persistent storage an the hard disk for cryptographic keys generated inside the TPM.

This Chapter shows the design and structure of the software layers between Java applications and the TPM. Before we address aspects of making TSS functionality available to Java, we provide an overview of the original TSS architecture and its functionality.

2.1 The TCG Software Stack Architecture

TPMs are required to provide protected capabilities and at the same time are designed as low cost devices. Due to their inexpensive nature, the internal resources and external interfaces are kept to a minimum. To nevertheless provide a certain level of usability, functionality and abstraction the TCG defines the TSS with different layers (see Illustration 1). Functions that require protected capabilities are implemented in the TPM while non-sensitive features which do not require hardware protection are implemented in software. To allow a common access to this Trusted Computing functionality, these software components are combined into the TSS and offer a standardized interface. This way, the TCG intends to provide a standard environment for applications.

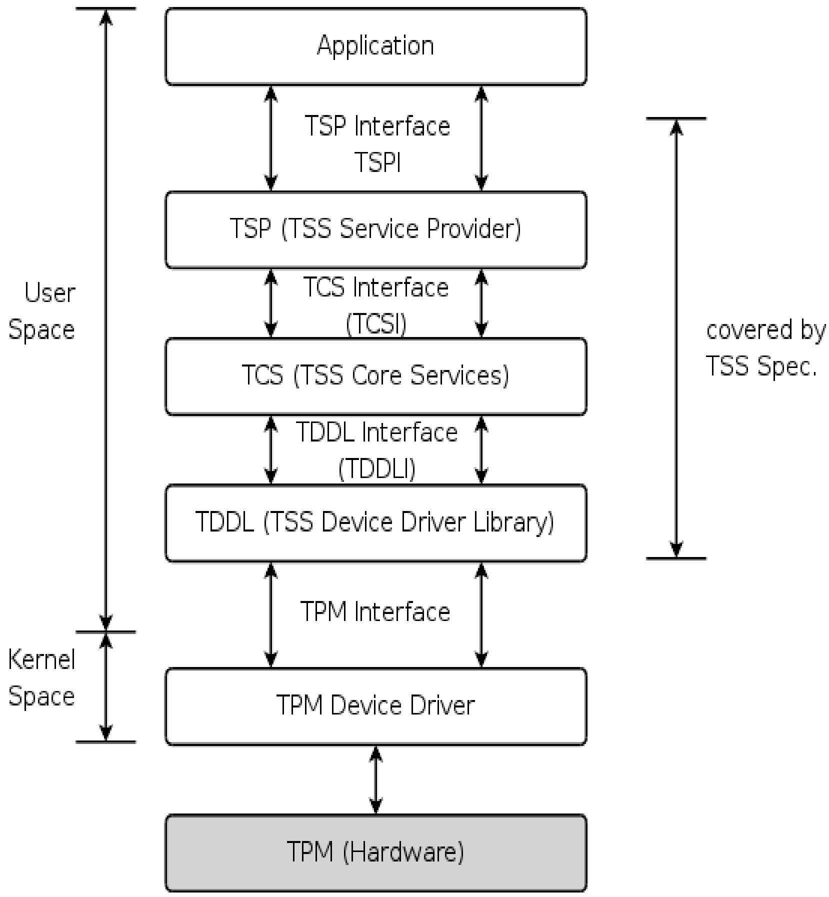

Illustration 1: TCG Software Stack Layers

2.1.1 Trusted Platform Module (TPM)

In case of the PC platform, the hardware TPM is part of the mainboard and can not easily be removed or replaced without destroying the hardware. It is typically connected to the rest of the system via the LPC bus. The functionality of this hardware device resembles that of a smart card. A tamper resistant casing contains low-level blocks for asymmetric key cryptography, key generation, cryptographic hashing (SHA-1) and random number generation. With these components it is able to keep secret keys protected from any remote attacker. Additional high-level functionality consists of protected non-volatile storage, integrity collection, integrity reporting (attestation) and identity management. Of special interest is that the TPM is a passive device, a receiver of external commands. It does not measure system activity by itself but rather represents a trust anchor that cannot be forged or manipulated.

2.1.2 TPM Device Driver (TDD)

The TPM device driver resides in the Kernel space. For a 1.1b TPM this driver is vendor specific since it just offers a proprietary interface to upper layers whereas 1.2 TPMs supports generic TPM Interface Specification (TIS) drivers. TIS provides a vendor independent interface to access TPM functionality. It depends on the platform and the operating system but the TDD may also support additional functionality such as power management. Nowadays, all major operation systems (*e.g.* Linux OS or Microsoft Windows Vista) ship with TIS drivers or even support them.

2.1.3 TSS Device Driver Library (TDDL)

The TDDL (Trusted Device Driver Library) resides in User space. From the user's point of view it exposes an OS and TPM independent set of functions that allow a basic interaction with the TPM. This includes sending commands as byte streams to the TPM and receiving the TPM's responses. The TCG specifies the TDDL Interface (TDDLI) as a required set of functions implemented in the TDDL. The intention was to offer a standardized TPM interface regardless of the TPM vendor and the accompanying TPM device driver. This ensures that different TSS implementations can communicate with any given TPM. In contrast, the communication between the TDDL and the TPM is vendor specific.

The TDDL is designed as a single-instance and single-threaded component.

2.1.4 TSS Core Service (TCS)

The Trusted Core Service (TCS) is a system service and there is a single TCS instance for each TPM. The communication with the TPM relies on the TDDL and ensures that commands are properly serialized. The TCG defined the TCS Interface TCSI that specifies the communication between the TCS and the Trusted Service Provide TSP (see Illustration 1).

The main features of the TCS are:

- **Key Management and Persistent Storage:** The TPM generates cryptographic keys but due to the low cost nature the internal memory (*i.e.* number of keyslots) is limited. With the key management component of the TSS it is possible to store keys in a persistent storage outside the TPM encrypted under a parent key. To do so, the user must provide this parent key before the TPM can create a new keypair. Before the TPM writes to the persistant storage it encrypts the new private key under its parent key to ensure that no unencrypted key leaves the TPM.

  The root of of the key hierarchy is the storage root key (SRK) which is generated at taking ownership and then stored inside the TPM permanently.

- **Key Cache Management:** To actually use a key inside the TPM it must be loaded in one of the TPM's keyslots. The Key Cache Manager is responsible to transfer keys from the TPM to the persistant storage and vice versa. For example, if a user key resides in the persistant storage, the key cache manager will fetch it into the TPM the next time the user makes use of a child key. Since the key handle remains the same the entire process is transparent to the user.

- **TPM Command Generation:** The TPM receives commands as byte streams. The Command Generator builds these byte streams and sends them to the TPM. It is also responsible for serialization of TPM commands in a proper way to avoid problems with concurrent accesses.

2.1.5 TSS Service Provider (TSP)

The TSS Service provider (TSP) is the highest abstraction layer in the TSS and offers services defined by the TCG to applications. Due to the design as a system library, the TSP directly links to applications. For different applications several TSPs can coexists side by sider and interact with one single TCS. Applications can access the TSP by a TCG defined TSP Interface (TSPI). In fact, this is a simple C style API with object oriented influences (see [Challener] for further information).

For the implementation, a context object serves as entry point to all functionality such as authorized and validated TPM commands, policy and key handling, data hashing, encryption, and PCR composition.

The TSP can also be used to integrate the TPM in cryptographic libraries like PKCS#11.

2.1.6 TSS Communication Mechanisms

The standard access to the TSS for applications is the TSP interface. Applications can directly link to the TSP library and use this interface to access the TCS. The TSP and the TCS can communicate either via local calls or via the SOAP interface. Local calls are mainly used for testing purposes whereas the SOAP communication covers a larger range of applications.

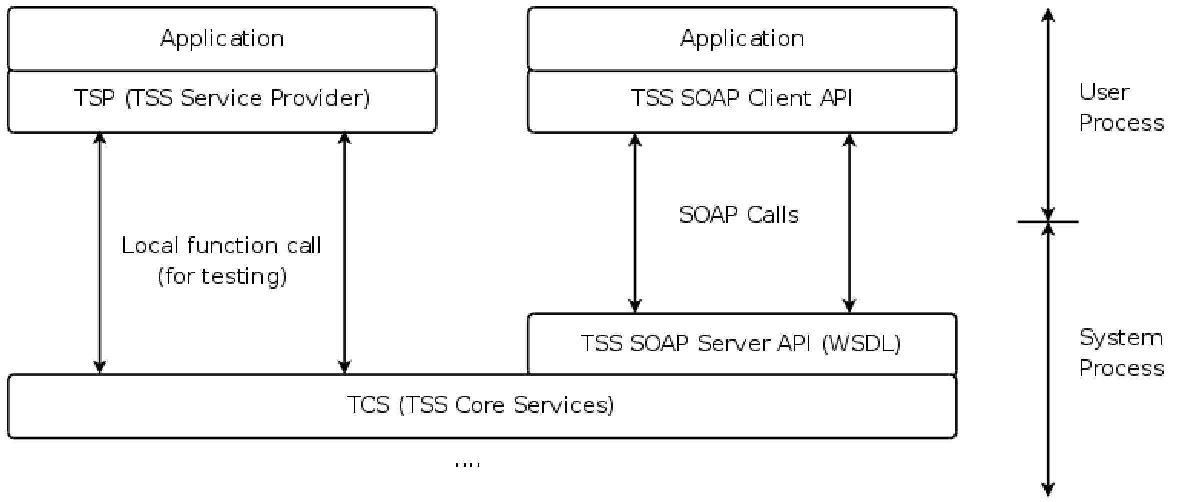

Illustration 2: TSS Access methods: local and SOAP

SOAP is a lightweight XML based protocol for the exchange of information from a sender to a receiver [SOAP] .

In 2007 the Trusted Computing Group (TCG) released an interface specification for this communication style by means of a Web Service Description Language (WSDL) file. It defines method names (and their parameters) which are applicable for the TSP to communicate with the TCS. Further, the WSDL file specifies how to encode SOAP messages: parameters for methods are to be *SOAP-encoded,* as defined in the W3C recommendation [SOAPENC].

Unfortunately, this particular encoding chosen by the TCG is neither recommended by the Web Service Interoperability organization [WSI] , nor supported by the popular Java SOAP Framework AXIS2 [AXIS2]. Additionally, if one compares the throughput in relation to the payload size of the SOAP messages, the *SOAP-Encoding* causes a significant loss of efficiency due to the unnecessary overhead of this specific encoding [SOAPIM]. The main drawback of *SOAP-Encoding* is the SOAP Data model which is not defined anywhere in a formal, machine parsable way [SOAPPRE].

A better way to allow integration of SOAP based communication into a Java binding for the TSS, would be the use of common *XML-encoding* (RPC/Literal) instead of *SOAP-Encoding* for the SOAP messages is proposed.

2.2 Integrate TSS Functionalities in Java

The aim of the Java API is to use and access the functionality of the TSS and the TPM within Java applications. On the one hand we need an object oriented application interface and on the other hand we want to interface to the hardware based services of the TPM. Several distinct approaches are possible.

Wrap an existing service of the native OS. This allows us to integrate into the existing system infrastructure provided by a native TSS. It is accessed by only a small Java layer. We call this approach ***jTSS Wrapper***.

Create a complete and pure Java TPM access software. We implement the TSS specification of all layers in pure Java. This implementation is simply referred to as ***jTSS***.

Application access to the TPM. The interface available to application developers is the same for both underlying implementations. It defines of data types, exceptions, and abstract methods. We refer to it as the ***jTSS API***.

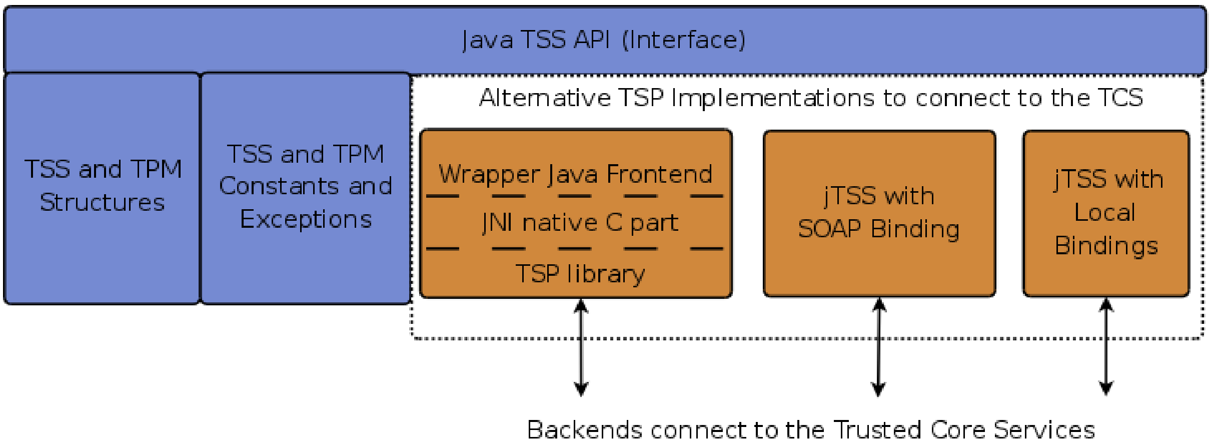

Illustration 3: The Java TSS Wrapper is split into frontend components (blue) and different backend implementations (orange).

2.3 jTSS Wrapper

One way to provide TSS functionality to Java is an additional layer on top of an existing TSS stack. Illustration 4 presents possible approaches in the scope of TCG's TSS specification. The blue layer represents the high level jTSS API that is used by applications. The orange boxes denote implementation components that are specific to the connection mechanism to interact with the TCS.

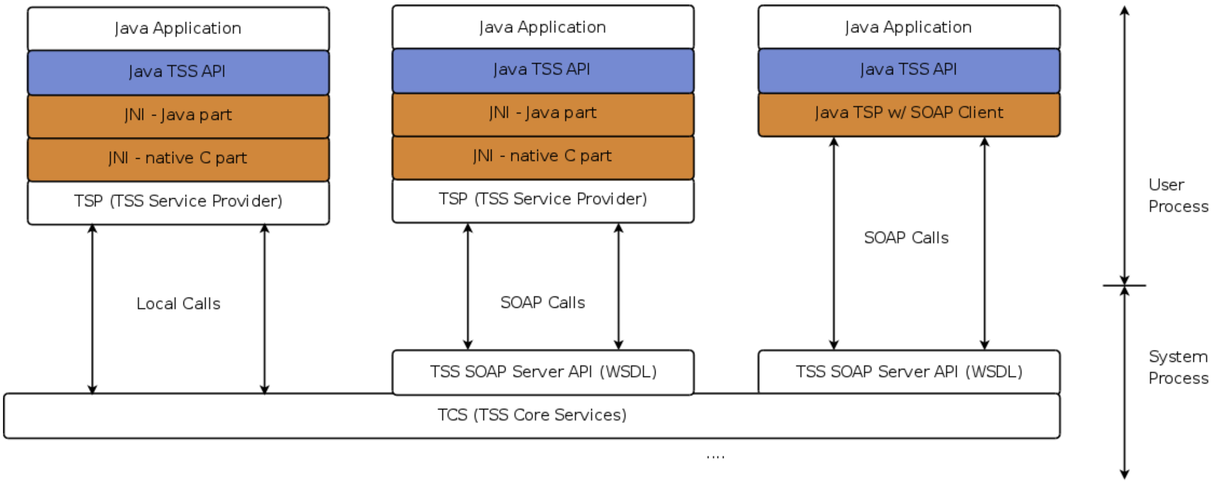

Illustration 4: Alternative Architectures for TSS Wrapping (left: full C stack, middle: full C stack with SOAP based connection, right:hybrid with Java TSP and C TCS)

The selection of a viable strategy depends on the availability of C-based components. At the time the jTSS Wrapper was originally devised no available C-stack featured a specification compliant SOAP interface[1]. Thus rendering the middle and rightmost architectures in Illustration 4 infeasible. Yet, the [TrouSerS] stack was openly available. For now it only supports local function calls but it has reached a good level of maturity. We therefore selected the leftmost architecture to build the jTSS Wrapper[2].

The jTSS Wrapper software package integrates the TSP service in Java. Therefore, we introduce the Java Native Interface layer (JNI) that wraps the implementation of the TrouSerS stack.

It consists of two parts: a native C part that directly accesses the TSP library and a Java interface that reflects the C functions and structures. The link between these two parts bases on an autogenerated module derived by [SWIG]. Building on this, the Java frontend abstracts several aspects of the underlying library such as data types and the conversion of error codes to exceptions. Java applications access the wrapper via Java JNI API which is a simple but powerful interface.

In the C environment applications and modules are responsible for the memory they allocate. So, the jTSS Wrapper copies data received from the TSS into Java objects and releases TSS memory before it returns the newly constructed Java objects to the

1 In the meantime, Open_TC partner Infineon is working towards such a stack.

2 Upcoming releases of TrouSerS will include a SOAP interface, thus making this feature also available to users of the jTSS Wrapper.

caller. Thereby, Java developers are relieved from the need to explicitly free TSS memory.

One disadvantage of the Wrapper approach is the higher complexity of the overall system. Any parameter is byte-order converted, passed on, processed, copied between processes, reconverted, and returned. Following this process, for instance in a debugger across language barriers is complex and challenging task. Another drawback is the influence of implementation errors in the C-based components to the program stability, *e.g.* memory leaks in the TSS.

On the other side the jTSS Wrapper perfectly fits in an existing TSS environment because it does not influence existing applications that rely on the TSS. It is actually just another application that interacts with the TSS to access the TPM.

This is especially useful when considering, that other software such as the OS requires TPM services as well, possible already at boot time. The need for an interface that handles both, resource management and concurrent access implies that this service cannot be implemented on the stack of running software alone, *i.e.* within a virtual machine. Thus jTSS Wrapper has the major advantage that it allows deployment on legacy operating systems which do not provide TPM virtualization. Further, one can access an already running TSS without changing the system. In the current implementation this is restricted to the case of Linux providing an instance of TrouSerS.

2.4 jTSS

An alternative approach to the Java Wrapper with the third party TSS is the implementation of a native Java TSS. This Section is dedicated this solution.

A TSS consists of two main parts, namely the Trusted Service Provider (TSP) and the Trusted Core Services (TCS). In the jTSS, both parts are implemented in Java.

The following Subsections briefly describe the individual components depicted in Illustration 5, starting at the hardware (TPM) level up to the Trusted Core Service (TCS) and the Trusted Service Provider (TSP).

2.4.1 Hardware Access

- **TPM and OS Driver**

  The TPM chip forms the lowest level of the stack and different vendors manufacture it according to the TCS specification. Although, there exists two different specifications (*i.e.* TPM 1.1b and TPM 1.2) jTSS supports both of them. Due to the the rapid development of the IT industry 1.2 TPMs will become dominant in the near future.

  The first software component that accesses the TPM is the OS driver that typically runs in Kernel mode. For the jTSS development we can assume that the driver is supplied either by the TPM vendor or is already part of the operating system. Modern 1.2 TPMs no longer need a vendor specific driver because they are accessible via a TIS (TPM Interface Specification) driver.

- **Trusted Device Driver Library (TDDL)**

  The TDDL is a standardized software layer that provides an abstraction of the underlying OS specific TPM interface. Due to the design of the TDDL one can easily add implementations for different systems.

  The jTSS can operate on both major Operating Systems used today. The Linux OS implements the TDDL such that it opens the TPM device file (/dev/tpm) provided by the underlying driver. Microsoft ships Windows Vista with a generic TIS driver that accesses the TPM via the so called Trusted Based Services (TBS). This service interface should allow similar access to the TPM as the device file under Linux does.

2.4.2 Trusted Core Service

To get an overview of the individual components that make up the TCS, Illustration 5 presents the main components and their interactions.

- **Parameter Block Generator and TPM Structure Parser**

  The TPM offers a byte stream oriented interface where TPM commands are marshaled into byte streams.

  The TPM specification defines the data exchange with the TPM by C elements, so all primitive data types (*e.g.* UINT32) have to be mapped to equivalent Java types and the C structures have to be modeled by Java classes. To send a TPM command we extract the necessary content from the Java class instance and serialized it into a byte stream. Vice versa, we unpack the response and decode it to Java objects.

- **Authorization Manager**

  The TPM is a low cost chip with a limited amount of internal resources. One of these resources are authorized sessions managed by the TSS. The authorization manager keeps track of them and swaps, evicts, or reloads TPM authorization sessions.

- **Event Manager and Event Log**

  The TCG specifies an event log message for the PCR extend operation. It is the task of the TCS to store, manage, and report this information.

  In general, the event log is not limited to events generated by the TSS. During boot, the BIOS measures the start and stores all log information in the ACPI memory. To provide a complete event log, the TSS collects this and other log entries (*e.g.* Integrity Measurement Architecture [Sailer]) stored by the OS. Currently, only a basic memory based event log is implemented.

- **Key and Credential Manager, Persistent System Storage**

  Applications might need to store keys permanently and the TCS offers a system wide persistent storage for that purpose. The Key Manager assigns a (possiby globally) unique identifier called UUID to every key and stores the key blobs in the persistent storage in the OS file system. I also retrieves and loads the keys. Applications can use this UUID as reference to the requested key.

  Further, the TCS manages credentials (i.e. X.509 certificates) such as the endorsement or the platform credential. By that, it ensures that all applications can access these credentials by a well defined mechanism. For example, the credentials are used as part of the CollateIdentity/ActivateIdentity cycle to create Attestation Identity Keys (AIKs).

- **TCS Context Manager**

  Applications allocate resources with every call to the TSS. The Context Manager is responsible for these resources and binds them to an application specific context.

- **TCSI API**

  This layer represents the standardized API of the TCS. The TSS specification defines this API in a C style fashion which was mapped to Java in a straightforward way.

- **TCS Server Module**

  The TCS is designed as a system service or system daemon. The TCS server component allows multiple applications to concurrently access the TSS. It accepts incoming connection requests from applications and passes them to the underlying layer. It ensures proper synchronization and allows only one thread to enter critical sections of the TCS.

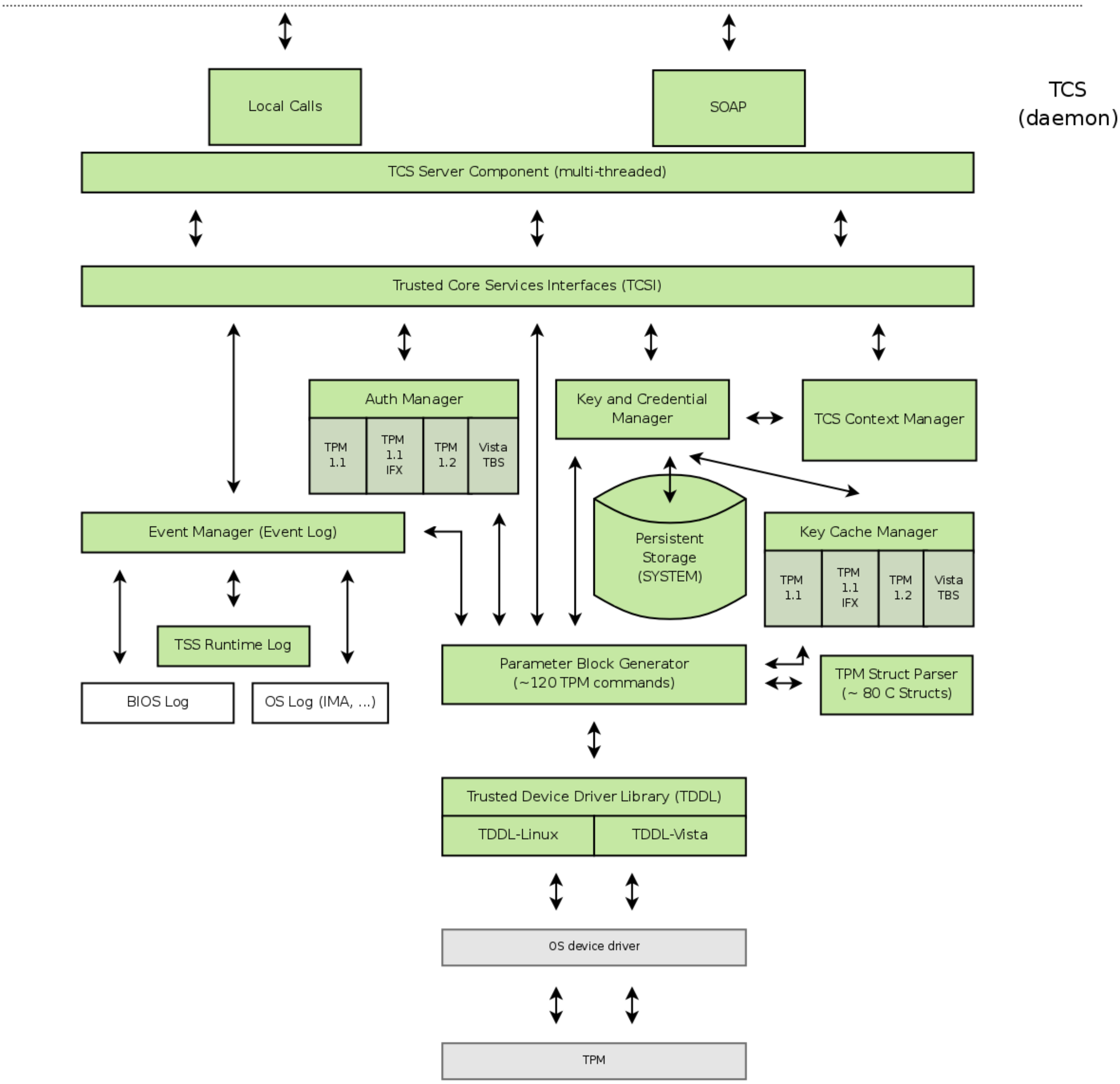

Illustration 5: Trusted Core Services Components. Requests from the TSP are received via one of the communication facilities provided by the TCS server component.

2.4.3 Simple Object Access Protocol SOAP

As mentioned above the TCG provides a standard for the communication between the Trusted Core Service TCS and the Trusted Service Provide TSP. One way for this communication is the SOAP protocol that bases on XML messages. Within the context of this application, SOAP is used to build a framework for simple RPC calls. A client (*i.e.* the TSP) send a request to a server (*i.e.* the TCS) and waits for a response message.

The above service-client architecture implies that we need a OS wide service that represents the TCS. We support the two major operating systems and therefore we actually need a Windows Service respectively a Linux Daemon for the server side. Both TCS representations have a predefined interface according to a WSDL file defined by the TCG. WSDL is the abbreviation for “Web Service Description Language” and specifies all remote method calls and their required parameters.

We can use the given WSDL file to derive the entire SOAP framework for the implementation of the communication. The problems with the SOAP encoding (see Section 2.1.6) forced us to use the Axis SOAP libraries by the Apache Foundation. Axis is not maintained any more and so this seems not to be the perfect solution.

- **Linux Daemon and Windows Service**

  There exists several ways to start and maintain a Java application in Windows and Linux but for consistency reasons we rely on the Apache Daemon implementation for both operating systems. These libraries provide an easy to use and solid foundation for the TCS with additional functionality, *e.g.* Log server events.

- **Implementation**

  The WDSL represents all methods and parameters for the communication between TCS and TSP. To actually use it within the TSP and TCS we can employ Apache Axis libraries and derive all necessary Java class files.

- **Communication**

  We have already mentioned that there exists a local interface besides the SOAP interface for the communication between TSP and TCS. The TSP is linked to the Java application on the top of the stack and can therefore decide whether to access the TCS via local calls or via the SOAP interface. This decision depends on the current appliance and is up to the user.

2.4.4 Trusted Service Provider

The TSP typically is designed as a library that is linked to an application. Illustration 6 provides an overview of the major building blocks of the jTSS Trusted Service Provider. Starting at the bottom of the TSP, the major components are:

- **TCS Bindings**

  Since the TCS can support different communication mechanisms, the TSP must offer the same, too. The TCS binding component provides an abstraction layer that allows to add communication components later on without requiring changes of upper layers of the TSP.

- **Authorization and Validation Component**

  The access to the TPM and the TPM's resources requires proper authorization. The TPM specification defines special authorization protocols used to establish authorization for those resources. The Authorization and Validation Component is responsible for creating and managing authorization sessions. Additionally, it validates response data from the TPM.

- **TSP Context Manager**

  Communication sessions with the TCS are mapped to contexts. The Context

Manager is responsible to keep track of context sessions and the management of the associated resources.

- **Key Manager and Persistent User Storage**

  The TSP maintains a key hierarchy where every TPM key has a parent key in the layer above. Before a user or an application can load a key from the user persistant storage the Key Manager establishes and verifies the entire key chain up to the Storage Root Key (SRK). Contrary to the system persistent storage, this TSP-layer storage is individual for every user of the system.

- **TSPI and TSP Working Objects**

  The top level interface of the TSP is called Trusted Service Provider Interface (TSPI) and is standardized in the TSS specification. It is common with all our implementations described in Section 6.

- **Transport Session Component**

  Transport Sessions are a new feature introduced in TPM specification 1.2. It allows the TSS to encrypt commands and data sent to the TPM. This provides protection against attackers who intercept the data transmitted over the system's LPC bus.

A native Java TSS implementation clearly reduces the number of involved components and dependencies for a TPM access. Consequently, this approach results in less side-effects from incompatible TSS implementations or different interpretations of the TSS specification. Moreover, a pure Java stack can easily be ported to other operating systems and platforms, *e.g.* embedded systems with TPM support. While vendor specific stacks limit themselves to a few specific TPM types, One of the main advantages of the jTSS is the ability to support TPMs from different manufacturers. This approach allows the reduction of the size and complexity if compared to the jTSS Wrapper. Due to the lower complexity, it is easier to debug and well-suited for educational and research purposes. It can fully exploit its advantages in fully virtualized environments, such as a compartment exclusively for the Java VM, with no concurrent accesses. It may also be used if the resources of the TPM are virtualized, *e.g.* TPM Base Services (TBS) in Windows Vista.

2.5 The Common jTSS API

The Java programming language evolved in the last years to a commonly accepted environment. The main advantages are a restrictive type and memory safety ideally suited for security relevant applications. Although, Trusted Computing became more and more important over the last years there is currently no support within Java.

An Application Programming Interface (API) is a interface for programmers. The design of an API is always a trade off between a restriction of features to keep it simple and to preserve a developers freedom. For the current purpose of the integration of TPM functionality in the Java language we have to meet a few additional requirements. The main design aspect is to cover the entire functionality envisioned by the TCG in this API without inconsistencies. Despite the complexity of the original specification we enable programmers to develop powerful applications with a clear and relatively easy to use interface.

Although, the basic concepts and functionality of the native TSP remains the same in its Java counterpart, several aspects were changed to meet the object oriented nature of Java. TSS entities such as contexts, keys, hashes, or the TPM are represented by actual Java objects. This relieves developers from object handles and memory management as required in the original TSP. Thus, developers who are already familiar with the TSPI should be able to use the Java interface without a steep learning curve because the design is similar to its C-based counterpart. The Java interface provides all the flexibility and features of the underlying stack to Java developers. Existing resources such as TSPI based C-code can therefore easily be mapped to Java.

With an abstract API, programmers can access the TSS without any knowledge of the actual implementation. This way, there is no need to change Java applications if the underlying mechanism of the TSS changes. Currently, developers of Trusted Computing Java applications can either use the jTSS Wrapper (see Section 2.3) or the jTSS (see Section 2.4) developed by IAIK.

2.5.1 Core Parts of the API

- **TcIContext**

  A context represents a connection to the TSS Core Services. One can either connect to a local or a remote TCS. A context allows to specify the connection host. The context creates all further TSS objects like policy objects and registers, loads or unregisters keys from the persistent storage. The context can close objects (release their handles), get information (capabilities) about the TCS as well as free TSS memory.

- **TcITPM**

  This class represents the TPM and parts of its functionality. It provides methodes to take or clear TPM ownership, read and set the TPM status, obtain random numbers from the TPM, access time stamping functions, or read and extend PCR registers. Aside from low level functions, *e.g.* trigger a TPM self test, it offers functions to create “attestation identities”. Further, it can do quote operations to attest the current state of the platform represented by the contents of the PCR registers.

- **TcIRsaKey**

  Instances of this class represent keys in the TPM's key hierarchy. It provides functionality to create a new key, load a key into a key slot of the TPM, or certify keys.

- **TcIEncData**

  This class provides access to the TPM's bind/unbind and seal/unseal functions which encrypt data with a TPM key. If this key is not migratable only the TPM that did the bind operation is able to unbind (*i.e.* decrypt) the data. It is computationally unfeasible to decrypt data if the TPM and therefore the according private key is not available any more.

  Sealing takes this concept a step further: This operation includes the platform configuration to encrypt data with a TPM key. By that, the sealed data can only be unsealed if the platform is in the state specified at seal time. The platform configuration is represented by the content of the TPM's PCRs.

- **TcIHash**

  This class provides access to the TSS's hash algorithm SHA1. That includes unkeyed hash calculation and verification as well as keyed hash functions, *e.g.* create signatures of data blocks with a TPM key.

- **TcIPcrComposite**
  The platform configuration registers (PCRs) can be used to attest the state of a platform (quote operation) or to seal data to a specific configuration. Instances of this class select one or more PCRs and hand them to the quote or seal functions.

- **TcIPolicy**

  The policy class handles authorization data for TSS objects such as keys. The authorization data consists of the SHA-1 hash of the user password. Note that different character encodings (ASCII, UTF-16LE Unicode, etc.) will hash to different values. Alternatively to setting a password, a pop-up windows will ask the user to enter the appropriate secret.

- **TcINvRam**

  This class stores the attributes of a region of non volatile RAM inside the TPM. It can be used for defining, releasing, reading or writing such a region. An example is the Endorsement Key certificate shipped with Infineon TPMs.

2.5.2 Input/Output Data Formats and Error Handling

The C-based implementation of the TSP handles and identifies errors on the return code. Java replaces this concept with Exceptions which encapsulate the errors returned from the TSS. This allows to handle TSS errors with conventional Java error handling mechanisms.

Due to flexibility reasons, the TSS returns generic byte arrays instead of concrete structures. This allows developers to use one single function to retrieve different types of data and treat the returned data correctly. The Java TSS Wrapper tries to convert the generic byte blobs into proper objects. If this is not possible some easy to use Java representations of the equivalent C structures are available. They provide developers with a simple mechanism to convert byte blobs from lower layers into objects. Programmers can use this to handle structures directly received from the TPM.

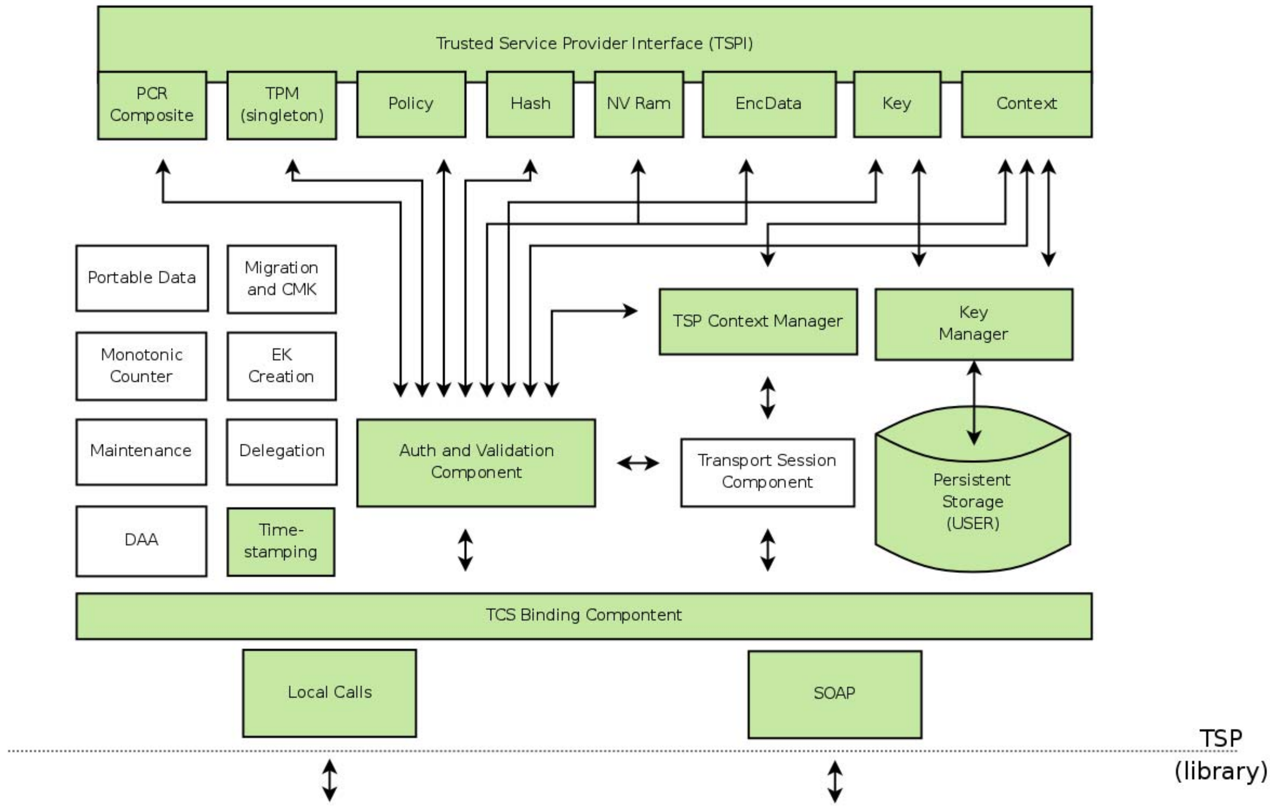

Illustration 6: Trusted Service Provider Components

3 IAIK jTSS – User and Installation Guidelines

3.1 Introduction

The IAIK jTSS stack is an implementation of the TCG Software Stack for the Java (tm) programming language. In contrast to approaches like the IAIK/OpenTC jTSS Wrapper, the IAIK jTSS does not wrap a C stack like TrouSerS but implements all the TSS layers in Java (tm).

A TCG Software Stack, as specified by the Trusted Computing Group (TCG (http://www.trustedcomputinggroup.org/)), is one of the main software building blocks of a Trusted Computing enhanced system.

Development of the IAIK jTSS is supported by the European Commission as part of the OpenTC project (Ref. Nr. 027635). The IAIK jTSS is developed and maintained at the Institute for Applied Information Processing and Communication (Institut fuer Angewandte Informationsverarbeitung und Kommunikation, IAIK (http://www.iaik.tugraz.at)) at Graz University of Technology (TU Graz (http://www.tugraz.at/)).

3.1.1 OpenTC Project

The Open Trusted Computing (OpenTC) consortium is an R&D project focusing on the development of trusted and secure computing systems based on open source software. The project targets traditional computer platforms as well as embedded systems such as mobile phones.

The goal of OpenTC is to reduce system-related threats, errors and malfunctions. The lack of platform security in today's computers has given rise to waves of successful attacks, resulting in severe damages to enterprises and potential failure of critical infrastructures.

The OpenTC consortium will define and implement an open Trusted Computing framework. The architecture is based on security mechanisms provided by low level operating system layers with isolation properties and interfaces to Trusted Computing hardware. These layers make it possible to leverage enhanced trust and security properties of the platform for standard operating systems, middleware, and applications.

For more information about the OpenTC project please refer to the OpenTC (http://www.opentc.net/) website.

3.2 1.2. A Word of Caution

The IAIK jTSS still is in early stages of development. It currently is regarded as experimental software targeted at research and educational environments. It therefore is discouraged to use IAIK jTSS in a production grade environment. Use the software at your own risk!

3.2.1 1.3. License

The IAIK jTSS is using a dual licensing model:

- For Open Source development, the IAIK jTSS is licensed under the terms of the GNU GPL version 2. The full text of the GNU GPL v2 is shipped with the product or can be found online at (GPL (http://www.gnu.org/licenses/gpl.html)).
- In all other cases, the "Stiftung SIC Java (tm) Crypto-Software Development Kit Licence Agreement" applies. The full license text can be found online at Stiftung SIC (http://jce.iaik.tugraz.at/sic/sales/licences/commercial). For pricing and further information please contact jce-sales@iaik.at (mailto:jce-sales@iaik.at).

jTSS SOAP supports depends on a number of third party libraries which come under different licenses, see chapter below for further information.

3.3 Current Status

As mentioned in earlier sections, the IAIK jTSS still is in early stages of development and therefore is not yet feature complete nor exhaustively tested.

For development, the following TPMs have been used:

- Infineon 1.2 TPM
- TPM Emulator from ETH Zurich (Software)

These TPMs have also been used for development or are reported to be compatible:

- Infineon 1.1b TPM
- Broadcom 1.2 TPM
- ST Microelectronics 1.2 TPM
- Atmel 1.1 TPM (limited)

Although all TPMs are based on the TCG TPM specification, some TPM models might behave a little different from other TPMs. The IAIK jTSS tries to abstract all these little twists and provide a consistent behavior to applications regardless of the actual underlying hardware TPM. In some cases however IAIK jTSS might fail on a TPM. To further enhance IAIK jTSS we rely on your feedback and potential contributions.

Due to the fact that IAIK jTSS is fully implemented in Java (tm), porting it to different operating systems becomes relatively easy. Currently, the following systems are supported:

- Linux (using TPM device drivers of recent 2.6 kernels)
- Microsoft Windows Vista (using Trusted Base Services)

Regarding TSS features, IAIK jTSS covers large parts of the TSS 1.1 specification and some parts of the 1.2 TSS specification. TPMs of version 1.2 are fully supported regarding their changes in resource management.

3.3.1 Features Currently Supported by IAIK jTSS

TSS Device Driver Library (TDDL). The TDDL API is targeted towards C applications, so instead we implement

- Linux support by accessing TPM device file and
- Windows Vista support by accessing Microsoft TBS.

TSS Core Services (TCS)

- Parameter Block Generator (PBG) covering all 1.2 TPM functions
- C structure parser covering all 1.2 TPM structures
- Authorization Manager (TPM 1.1 and 1.2 support)
- Key Cache Manager (TPM 1.1 and 1.2 support)
- Event Manager ("in memory" event log)
- Persistent System Storage
- TCS Interface (TCSI) layer
- TCS system service with SOAP interface

TSS Service Provider (TSP)

- TPM command authorization (OIAP, OSAP, ...) and validation component
- TSS Service Provider Interface (TSPI) modified for Java use
- Attribute Functions (Get/SetAttrib)
- TPM (AIK creation, ownership, capabilities, event log, status, random data, quote, PCR extend, ...)
- TSP Context (context management, object creation, selected PS functionality, ...)
- Encrypted Data (Bind/Unbind, Seal/Unseal)
- Hash (hash computation, signature verification, ...)
- RSA key (creation, loading, extracting, ...)
- PcrComposite (selection, setting and getting PCRs including 1.2 features like l ocality, ...)
- Policy (creating, managing and assigning policies)
- Time Stamping (TPM 1.2 only)
- NV Storage read access
- SOAP interface

3.3.2 TSS Specified Features not included in this Release

- Delegation
- Key Migration and CMKs
- NV Storage (general support)
- TPM Maintenance (vendor specific)
- Monotonic Counters
- Revocable EKs and late EK creation
- Direct Anonymous Attestation (DAA)
- Transport Sessions

3.3.3 Known Issues

As with all experimental software that is in early stages of development, also IAIK jTSS has some known issues. To make sure that these known problems do not become pitfalls for you when developing Trusted Computing applications they are described here:

- TSS_SECRET_MODE_NONE is currently not supported by IAIK jTSS. That means that e.g. key objects can not be created without specifying a secret. To work around this issue you can use the TSS_WELL_KNOWN_SECRET as the entity secret in such cases.

3.4 Requirements

3.4.1 Java (tm) Environment

To use the IAIK jTSS you need to have a Sun Java (tm) Environment of version 5 or later. Earlier Java (tm) versions do not provide the required cryptographic functionality. Compatibility with other Java vendors is unknown and untested.

3.4.2 JCE Unlimited Strength Jurisdiction Policy Files

To make full use of the cryptographic capabilities of the JCE, the Unlimited Strength Jurisdiction Policy Files have to be installed. This is a requirement for the TSS to be able to handle TPM RSA keys. In case you experience errors like "Illegal key size or default parameters" chances are high that these policy files are not (or not correctly) installed.

3.4.3 Hardware TPM or TPM Emulator for Linux

To make use of IAIK jTSS you require either a hardware TPM or the TPM emulator from ETH Zurich TPM Emulator (https://developer.berlios.de/projects/tpm-emulator/).

The TPM emulator is a software package for Linux operating systems providing TPM functionality as a pure software implementation. It is especially useful for testing and development on systems where no hardware TPM is available. The emulator consists of a Linux kernel module and a user space daemon implementing the actual TPM functionality. For details on how to set up and configure the TPM emulator please consult the documentation that is included in the emulator package. Note that the time stamping is not working correctly in TPM emulator 0.5 or earlier.

In case you have a hardware TPM, you have to ensure that a proper Linux kernel driver for your TPM is loaded. Recent 2.6 kernels come with drivers for all major TPM manufacturers. For 1.2 TPMs, the TIS driver might be the way of choice to access your TPM.

No matter if you are using a hardware TPM or the TPM emulator, a device file called /dev/tpm (or /dev/tpmX) will show up. If you do not have this file, the TPM can not be accessed by the TSS.

3.4.4 Microsoft Windows Vista

The IAIK jTSS also includes support for Microsoft Windows Vista. In this case the TPM is accessed via the Trusted Base Services (TBS) of Vista. The TBS provide a very thin abstraction layer for TPM access. By default, Vista only comes with support for 1.2 TPMs. If your TPM is supported by Vista and if it can be accessed via the TBS, the IAIK jTSS should be able to communicate with your TPM on Vista systems.

Note that the default configuration of Vista blocks some TPM commands at the TBS level. Among these are commands for quoting and PCR access. You have to use the group policy editor to unblock this functions. For details please refer to the Microsoft Technet (Vista TPM Functions (http://technet.microsoft.com/en-us/windowsvista/aa905092.aspx)).

3.5 Setup and Usage

There are two ways to operate the IAIK jTSS:

- With local bindings, the TSP layer directly calls the TCS methods. This is well suited for development, experimenting and debugging. As a drawback, the Java VM must have proper access rights to the TPM device. We recommend you to use this to gain initial experience with IAIK jTSS.
- With SOAP bindings, the TSP will call the TCS via a web service interface. The TCS will run as system service (daemon). Once installed, any unprivileged application can access it.

In this chapter we discuss how to use the local bindings. You will find a detailed documentation on the SOAP bindings further below.

IAIK jTSS comes in pre-compiled form. In the lib subdirectory, you will find four jar libraries:

- *iaik_jtss_tsp.jar* This is the TSS Service Provicer (TSP) library you have to include in the classpath of your Java (tm) applications to make use of the TPM. The TSP library provides the programming API to be used in applications when interacting with the TPM.
- *iaik_jtss_tsp_soap.jar* The library that provides the SOAP support for the TSP.
- *iaik_jtss_tcs.jar* This library contains the TSS Core Services (TCS). Typically, the TCS would run as an independent system service. Alternatively it can be l inked to your TC aware application just like the TSP library. Note that all TPM interaction is done via the TSP library.The TCS is not designed to be used directly in your applications.
- *iaik_jtss_tcs_soap.jar* The library that provides the SOAP support for the TCS.
- Before use, a few basic settings need to be configured in *jtss_tcs.ini* resp. *jtss_tsp.ini*. The .ini files must reside in the same directory as the corresponding library file. For both libraries the persistent storage has to be configured. In addition, the binding interface between TSP and TCS must be set. The default are local bindings with the type set to *iaik.tc.tss.impl.java.tsp.TcTssLocalCallFactory*. if you wish to use the SOAP I nterface, set it to *iaik.tc.tss.impl.java.tsp.TcTssSOAPCallFactory*.

Aside from linking these jar libraries to your TC aware application (which essentially means adding them to the classpath) there are no further setup steps required.

In the src subdirectory you can find the entire source code of IAIK jTSS. Details on the organization of the source code are given in the Technical Documentation section.

Test the TCS TSP communication under Linux. You can test the TCS implementation with: `user@localhost:jTSS$ sudo bash tests/run_tests.sh`

Execute this test as root or adapt the access permissions to the TPM device if you use local bindings.

Test the TCS TSP communication under Windows Vista. You can test the TCS implementation with: `c:\>jTSS> tests\run_tests.cmd`

Execute this test from a command prompt with elevated administrative privileges if you use local bindings.

3.6 API Documentations and Sample Code

To get an overview of the concepts and the general API usage of a TSS it is recommended to consult the TSS Specification (https://www.trustedcomputinggroup.org/specs/TSS/). Additionally, the IAIK jTSS comes with a JavaDoc API documentation located in the doc subfolder. This documentation comes in two different flavours: The javadoc_all directory contains the JavaDoc for the entire IAIK jTSS. For developers that are only using the TSP layer and its highlevel API, the javadoc_tsp contains all relevant information. This documentation tree is a subset of the javadoc_all tree. It covers the TSP level API that is meant to be used by application developers.

Additionally to the provided JavaDoc, some example code demonstrating the basic usage of IAIK jTSS is included in the src/jtss_tsp/src_tests subfolder. It contains a set of jUnit test cases which can be used as a basis for own developments. A precompiled version of this test code is located in the tests subfolder. A shell script to run the tests is included.

3.7 Technical Documentation

This section provides a brief overview of technical aspects of IAIK jTSS.

3.7.1 Architecture Overview

Conforming with the TCG TSS specification, IAIK jTSS consists of two major parts: The TSP and the TCS. The TSP library is the entity that provides application developers with an API that allows access to all the TPM functions. The TSP is designed to be linked to an application that wants to make use of a TPM. The TCS is intended to be the only entity that directly accesses the TPM. As a consequence, the TCS is meant to be implemented as a system service or daemon. It is responsible for creating the TPM command streams, TPM command serialization, TPM resource management, event log management and the system persistent storage.

3.7.2 Source Code Overview

The source code of IAIK jTSS is split into three parts:

TSS Service Provider (TSP). As mentioned in previous sections, the TSP is the part that provides application developers with an API for accessing TPM functionality. In IAIK jTSS the API part is defined as a set of interfaces located in the `iaik.tc.tss.api` package. The `iaik.tc.tss.impl` package holds the actual implementations of the interfaces defined in the api package. The `impl` package holds sub packages containing different types of TSP implementations. The `java` sub package e.g. contains a TSP completely written in Java (tm). Other sub packages could e.g. contain implementations such as a JNI implementation that interfaces a TSP written in C like the TrouSerS TSS. The key benefit of having split the API and the implementation is that the applications developed on top of the TSP can easily be switched from one underlying TSP implementation to another by simply changing the factory that creates TSP level objects.

The layout of the TSP API package is like this:

- `iaik.tc.tss.api.tspi` - contains the object oriented TSP interface of IAIK jTSS derived from the TSS specification. The package contains interfaces for all the object types like Context, TPM, RsaKey, Hash or EncData defined in the TSS spec.
- `iaik.tc.tss.api.structs.tsp` - contains TSP level data structures as defined by the TSS spec
- `iaik.tc.tss.api.exceptions.tsp` - contains TSP level exceptions
- `iaik.tc.tss.api.constants.tsp` - contains TSP level constants and error codes

TSS Core Services (TCS). The TCS is the component that directly interacts with the TPM. In a typical TSS implementation, this component is a daemon or system service. The current implementation of the IAIK jTSS implements the TCS as a library.

The layout of the TCS package is as follows:

- `iaik.tc.tss.impl.java.tcs.authmgr` - This package contains the authorization manager component. It is responsible for the management of TPM auth sessions (caching and auth session swapping). It contains implementations for different TPM types and operating systems. These implementations are derived from a common base class. The actual implementation is selected based upon the systems TPM and OS version.
- `iaik.tc.tss.impl.java.tcs.credmgr` - The credential manager contained in this package contains all functions related to credentials (e.g. extracting credentials from IFX TPMs or the MakeIdentity function).
- `iaik.tc.tss.impl.java.tcs.ctxmgr` - This package contains the TCS context manager. The purpose of this component is to keep track of established TCS contexts.
- `iaik.tc.tss.impl.java.tcs.eventmgr` - This package contains the event manager component of the TCS. The event manager is responsible for storing and managing TSS event log entries.
- `iaik.tc.tss.impl.java.tcs.kcmgr` - This package contains the key cache manager. Some TPM implementations support key swapping in case the TPM key slots are depleted. The package contains implementations for different TPM versions. Additionally, this package holds code that manages all operations involving TPM keys. This includes the translation of TCS level key handles to TPM level key handles.
- `iaik.tc.tss.impl.java.tcs.pbg` - This package contains the parameter block generator. This is the TSS component that creates the command byte streams that are sent to the TPM.
- `iaik.tc.tss.impl.java.tcs.sessmgr` - This package provides session management as defined in the 1.2 TPM specification.
- `iaik.tc.tss.impl.java.tcs.tcsi` - This package contains the TCS interface (TCSI) being the TCS API used by callers (such as the TSP).
- `iaik.tc.tss.impl.java.tcs.tddl` - This package contains the TDDL for different operating systems. The TDDL is the layer that directly interacts with the TPM driver (e.g. via a device file or some other OS specific mechanism).

Common parts shared by TSP and TCS. There are several components that are required by both, the TSP and the TCS. Consequently, these components are located in a common source folder. The common components include e.g. constants for the TPM and TCS, TSS and TPM level structures, the persistent storage implementation, common crypto building blocks and utilities.

The provided persistent storage (PS) implementation is to be considered a demonstrator, and should not be used in a production environment. It uses the OS file system (FS) as data repository. In the .ini files, two different directories for both storages (system and user) must be specified. There must be a single system storage for the TCS and a user storage for each user (for instance */home/<username>/.tpm/user_storage*). When ownership of the TPM is taken, the storage root key (SRK) will be stored in the system storage (without the private key part).

Care must be taken with FS access rights to protect the storage. While the directory structure will automatically be created upon usage, it is a good idea to create the directories and set the permissions before starting jTSS. Depending on usage requirements a specific implementation might be necessary. Therefore, custom Java classes for persistent storage can be implemented and configured in the .ini files. Any implementation must implement the *iaik.tc.tss.impl.ps.TcITssPersistentStorage* interface.

Note, that in general the TSS specifications require the application programmer to take care that a valid key hierarchy is created and maintained in the storage.

3.8 SOAP Bindings

3.8.1 Introduction

The `Trusted Computing Group` specifies the communication between the Trusted Core Service (TCS) and the Trusted Service Provider (TSP) in the TSS Specification (https://www.trustedcomputinggroup.org/specs/TSS/tss12_Header_File_final.zip). One of these ways of communication is the Simple Object Access Protocol (SOAP). It is an XML based protocol that provides additional functionality if compared to simple RPC calls. The interface of the communication is specified in an XML document called Web Service Definition Language (WSDL) file which defines the procedure calls and their according parameters.

The TCS is a daemon that runs as a simple webserver and this package contains all necessary libraries for the entire SOAP communication. To specify parameters for the TCS and the TSP one can find further information in the *lib/*.ini* files under section *[SOAP]*.

TSP and TCS need additional 3rd party libraries that provide support for the SOAP communication. One can find a list with the versions and the according license model of these libraries in Section "*Versions and Licences of the Required Libraries*".

3.8.2 The Trusted Core Service under Linux

We use the Apache Commons Daemon Java library (Apache Daemon (http://commons.apache.org/downloads/download_daemon.cgi)) to start the Java TCS as Linux system daemon. In Ubuntu, these libraries are called *jsvc* and *libcommons-*

daemon-java and you can install them with the package manager.

We provide a script called *tcs_daemon.sh* in the `soap` directory of jTSS to start, restart, and stop the TCS daemon. Ensure to have a proper working TPM and execute these scripts as root:

Start the TCS as daemon

Start the TCS, detach it from the terminal and display the debug output in the terminal. "Detaching" means that the TCS keeps running if the terminal terminates. Additionally, the debug output (Std and Err) can be found in the file *log/out.log*. `user@localhost:jTSS$ sudo bash soap/tcs_daemon.sh`

Stop the TCS daemon

Stop the TCS daemon if it is running. `user@localhost:jTSS$ sudo bash soap/tcs_daemon.sh stop`

Start the TCS but do not detach it from the terminal

Display debugging information of the TCS and the entire SOAP communication in the terminal. You can terminate the TCS by pressing *<Ctrl>* *c*. `user@localhost:jTSS$ sudo bash soap/tcs_daemon.sh f`

Restart the TCS

Stop the TCS if it is running and immediately start it again. `Just start the TCS if it is not running. user@localhost:jTSS$ sudo bash soap/tcs_daemon.sh restart`

Print this document

`user@localhost:jTSS$ bash soap/tcs_daemon.sh help`

3.8.3 The Trusted Core Service under Windows Vista

The TCS is installed as a Windows Service. Start a windows command prompt with elevated administrative privileges and navigate to the jTss directory. NOTE: If you log off or restart your machine the TCS will still run. Further, ensure to surround a user defined path with quotation marks if it contains any spaces *e.g.* `"c:\this is a\path to my\script.bat"`. The delivered "soap/ext_libs/prunsrv.exe", and "soap/ext_libs/tcsdaemonw.exe" are taken from the the Apache Tomcat servlet container and provide start, stop, and restart functionality. The licenses for both can be found at the Apache Tomcat Homepage (Tomcat License (http://www.apache.org/licenses/LICENSE-2.0)).

Start the TCS as Windows Service

This script installs and starts the TCS as a Windows Service. All debugging information is written to *log\out.txt* and *log\err.txt*. `c:\>jTSS> soap\install.bat     start`

Stop the TCS Windows Service

This script stops the running TCS Windows Service. Keep in mind that it just stops the Service and does not remove it from Windows' Service list. `c:\>jTSS> soap\install.bat stop`

Remove the TCS Windows Service

If necessary, stop the TCS Service and remove it from Windows' Service list. `c:\>jTSS> soap\install.bat remove`

Restart the TCS Windows Service

Stop and remove the Service if it is running and immediately start it again. If it is not running just start it.

```
c:\>jTSS> soap\install.bat restart
```

Print this document

```
c:\>jTSS> soap\install.bat help
```

3.8.4 SOAP Package Structure

In the following we shortly describe the package structure of the SOAP implementation.

- `iaik.tc.tss.impl.java.tcs.soapservice.ConvertDataTypesServer.java` - Translate the datatypes used in the SOAP protocol to the datatypes used by the TCS and vice versa.
- `iaik.tc.tss.impl.java.tcs.soapservice.TSSCoreServiceBindingImpl.java` - Implement the wrapping of the TCS parameters to transport them via SOAP.
- `iaik.tc.tss.impl.java.tcs.soapservice.server.StartAxisServer.java` - Start the AXIS Server that provides a SOAP interface for all TCS functions.
- `iaik.tc.tss.impl.java.tcs.soapservice.serverties` - Contains the autogenerated Java files derived from the WSDL file.
- `iaik.tc.tss.impl.java.tsp.tcsbinding.soapservice.ConvertDataTypesClient.java` - This class implements the same methods as the corresponding file ConvertDataTypesServer.java on the server side.
- `iaik.tc.tss.impl.java.tsp.tcsbinding.soapservice.ConvertRemoteExceptions.java` - Unwrap the SOAP exceptions to get the nested TSS Exceptions.
- `iaik.tc.tss.impl.java.tsp.tcsbinding.soapservice.TcTcsBindingSoap.java` - Unwrap the parameters received from the SOAP network to use it in the TSP.
- `iaik.tc.tss.impl.java.tsp.tcsbinding.soapservice.clientstubs` - Contains the autogenerated Java files derived from the WSDL file.

3.8.5 Generate the WSDL File

As there are some missing functions in the WSDL files provided by (TSS Specification (https://www.trustedcomputinggroup.org/specs/TSS/tss12_Header_File_final.zip)) we have to modify it. To do so, extract the *tcs.wsdl* from (TSS Specification (https://www.trustedcomputinggroup.org/specs/TSS/tss12_Header_File_final.zip)) and copy it to the *soap* directory. Then apply the patch: `user@localhost:jTSS/soap$ patch -p0 tcs.wsdl tcs.wsdl.patch`

The patch process detects a previous patch of this file. Therefore press *y* to apply the patch anyhow.

Changes in the patched *tcs.wsdl* are now clearly marked with

<!-- Begin: Additional implementation as it is

not specified in the origin WSDL file -->

Here is the new code

<!-- End: Additional implementation as it is

not specified in the origin WSDL file -->

3.8.6 Generate SOAP Jars

Use the *build.xml* file in the *src* directory to get the jar files for the jTss with SOAP support. `user@localhost:jTSS/src$ ant jars_soap`

First, this task builds the complete jTSS Stack without any SOAP support. Then it creates the Java framework from the WSDL files and compiles these files. Finally, it generates two additional jar files: one for the SOAP support in the TCS and the other for the SOAP support in the TSP.

3.8.7 Versions and Licences of the Required Libraries

The following external libraries are required to start the TCS with SOAP support under Windows Vista and Linux OS.

1. JavaBeans Activation Framework Version 1.1.1

Download:

Sun JavaBeans (http://java.sun.com/products/javabeans/jaf/downloads/index.html)

License:

Sun JavaBeans License (http://developers.sun.com/license/berkeley_license.html)

Contains:

activation.jar

2. Axis Version 1.4 final

Download:

Apache Axis (http://ws.apache.org/axis/)

License:

Apache Axis License Version 2 (http://commons.apache.org/license.html)

Contains:

axis-ant.jar `axis.jar` *commons-discovery-0.2.jar* `commons-logging-1.0.4.jar` *jaxrpc.jar* `log4j-1.2.8.jar` *saaj.jar* `wsdl4j-1.5.1.jar`

3. Commons Daemon Version 1.0.1

Download:

Apache Daemon (http://commons.apache.org/downloads/download_daemon.cgi)

License:

Apache Daemon License Version 2 (http://commons.apache.org/license.html)

Contains:

commons-daemon.jar

4. JavaMail API Version 1.4.1

Download:

Sun JavaMail (http://java.sun.com/products/javamail/)

License:

COMMON DEVELOPMENT AND DISTRIBUTION LICENSE (CDDL) (http://www.opensource.org/licenses/cddl1.php)

Contains:

mail.jar

3.9 Further Help

This software is provided "as is". However, a mailing list trustedjava-support@lists.sourceforge.net (mailto:trustedjava-support@lists.sourceforge.net) is maintained at Trusted Computing for the Java (tm) Platform (http://trustedjava.sf.net/) to assist users and to allow users to help each other. You are invited to join the discussion, but kindly take a look at the mailing list archive before posting a question.

3.10 Copyright Notice

The copyright for contents of the IAIK jTSS package, including all related documentation, is owned by IAIK (http://www.iaik.tugraz.at), Graz University of Technology.

The API documentation (JavaDoc) is partially based on the descriptions and documentation contained in the TPM and TSS specifications of the TCG. Where possible, line numbers pointing to these specifications are included in the API documentation.

3.11 Trademarks

Java (tm) and all Java (tm) based marks are a trademark or registered trademark of Sun Microsystems, Inc, in the United States and other countries. All other trademarks and copyrights are property of their respective owners.

3.12 Revision History

date	version	comment
2008/04/17	0.3	SOAP interface, NV read access, additional test cases, bug fixes
2007/08/31	0.2	persistent storage, time stamping, bug fixes
2007/04/24	0.1	initial release

4 jTSS Wrapper Usage and Installation Guidelines

4.1 Introduction

Trusted Computing, as specified by the Trusted Computing Group (TCG, http://www.trustedcomputinggroup.org/), comprises multiple layers of hard and software. While the hardware consists of the Trusted Platform Module (TPM) and related trusted building blocks, the main software components include the TPM hardware driver and a Trusted Software Stack (TSS). This TSS is typically developed in pure C and can therefore not directly be used from other languages such as Java (tm). For that reason, the IAIK/OpenTC jTSS Wrapper provides language bindings for Java (tm). The goal is to make the Trusted Service Provider Interface (TSPI) layer of the TSS stack available to Java (tm) developers, by wrapping a complete, functional system stack with a Java (tm) interface.

Development of the IAIK/OpenTC jTSS Wrapper is supported by the European Commission as part of the OpenTC project (Ref. Nr. 027635). For more information about the OpenTC project please refer to the OpenTC Project section below.

The IAIK/OpenTC jTSS Wrapper is developed and maintained at the Institute for Applied Information Processing and Communication (Institut fuer Angewandte Informationsverarbeitung und Kommunikation, IAIK, http://www.iaik.tugraz.at/) at Graz University of Technology (http://www.tugraz.at/).

4.2 OpenTC Project

The Open Trusted Computing (OpenTC) consortium is an R&D project focusing on the development of trusted and secure computing systems based on open source software. The project targets traditional computer platforms as well as embedded systems such as mobile phones.

The goal of OpenTC is to reduce system-related threats, errors and malfunctions. The lack of platform security in today's computers has given rise to waves of successful attacks, resulting in severe damages to enterprises and potential failure of critical infrastructures.

The OpenTC consortium will define and implement an open Trusted Computing framework. The architecture is based on security mechanisms provided by low level operating system layers with isolation properties and interfaces to Trusted Computing hardware. These layers make it possible to leverage enhanced trust and security properties of the platform for standard operating systems, middleware, and applications.

For more information about the OpenTC project please refer to http://www.opentc.net/.

4.3 A Word of Caution

When experimenting with a real TPM, please keep in mind that the IAIK/OpenTC jTSS Wrapper is currently experimental software. If you are using your TPM in a real production environment, the use of the IAIK/OpenTC jTSS Wrapper is discouraged. No guarantees for data protected by the TPM can be made. Use the software at your own risk!

4.4 License

The IAIK/OpenTC jTSS Wrapper is using a dual licensing model:

- For Open Source development, the IAIK/OpenTC jTSS Wrapper is licensed under the terms of the GNU GPL version 2. The full text of the GNU GPL v2 is shipped with the product or can be found online at: http://www.gnu.org/licenses/gpl.html
- In all other cases, the "Stiftung SIC Java (tm) Crypto-Software Development Kit Licence Agreement" applies. The full license text can be found online at: http://jce.iaik.tugraz.at/sic/sales/licences/commercial. For pricing and further information please contact mailto:jce-sales@iaik.at.

4.5 IAIK/OpenTC jTSS Wrapper vs. IAIK jTSS

Since version 0.3, IAIK/OpenTC jTSS Wrapper is no longer a standalone package but it is an addon to the IAIK jTSS. IAIK jTSS is a TSS completely written using the Java (tm) programming language while IAIK/OpenTC jTSS Wrapper provides Java (tm) bindings for the TrouSerS TSS. To make switching between the wrapper and the full Java (tm) stack as simple as possible, both packages have to use the same API (TSP interface or TSPI). For that reason, IAIK/OpenTC jTSS Wrapper version 0.3 was modified to use the same top level API as the IAIK jTSS. As a consequence, applications developed for older version of IAIK/OpenTC jTSS Wrapper have to be modified to work with the new API. A porting guide is included with IAIK/OpenTC jTSS Wrapper that provides all required information for application porting.

4.6 Technical Documentation

This section deals with the technical aspects of the IAIK/OpenTC jTSS Wrapper. After outlining the basic architecture, this section deals with the requirements and the installation procedure.

Development of the IAIK/OpenTC jTSS Wrapper is done under Linux using IBM's TrouSerS TSS stack (http://trousers.sourceforge.net/) and hardware TPMs as well as the TPM Emulator from ETH Zuerich (https://developer.berlios.de/projects/tpm-emulator/). Since all software components are publicly available they provide an ideal playground for everyone who is interested in getting a "hands on" experience with Trusted Computing even if there is no hardware TPM available.

The following sections will also provide some instructions about how to install the TPM Emulator and the TrouSerS TSS stack.

4.6.1 Current Status

The IAIK/OpenTC jTSS Wrapper is currently considered almost feature complete with respect to the TSS 1.1 specification. That means that the TSPI layer of the TSS stack (TrouSerS) is fully made available to Java (tm) developers in an object oriented fashion. The only missing parts are the callback functions Tspicb_*. Those callback functions are not required to make full use of the TSS as they only provide a mechanism to customize the behavior of the TSS.

4.6.2 Architecture

The following table provides an outline of the architecture of IAIK/OpenTC jTSS Wrapper. The layers are described from the lowest layer, the TPM, upwards.

Layer	Comment
jTSS TSP	This is the layer actually used by developers. It is handwritten and implements the TSPI API as provided by the standalone IAIK jTSS thereby making switching between the wrapper and the standalone jTSS simple.
JNI (Java (tm))	This is a very thin layer that provides a flat Java (tm) interface of the underlying native interface. At this level you still have to cope with pointers and other low level aspects of the underlying C libraries. This layer is only used by the object oriented jTSS layer above.
JNI (native C)	The native C part of the JNI layer is largely generated with SWIG (http://www.swig.org/). The required SWIG interface files are include with the source or generated by a shell script from the TSS headers.
TSS	The native C TSS stack. The lowest layer of the TSS directly interacts with the TPM device driver while the highest layer provides the TSP interface.
TPM device driver	The device driver for the specific TPM.
TPM	The trusted platform module (hardware) forms the lowest layer.

4.6.3 External Requirements

TSS Stack

As stated earlier, IAIK/OpenTC jTSS Wrapper was developed using IBM's TrouSerS TSS stack. At the time of this writing, TrouSerS is the only publicly available TSS stack for Linux. As a consequence, TrouSerS is a requirement to use the IAIK/OpenTC jTSS Wrapper. In theory, any other TSS stack that complies with the TCG specifications should work as well. However, this has not yet been tested and any feedback on this topic would be welcome. From IAIK/OpenTC jTSS Wrapper ver. 0.3 onwards at least TrouSerS 0.2.9 is required.

Hardware TPM or TPM Emulator

For development, a software TPM emulator as well as hardware TPMs have been used. Any hardware TPM should be supported, as long as a Linux Kernel driver is available for the TPM and the driver conforms with the interface expected by TrouSerS.

Java (tm) JRE 1.5 or above

The IAIK/OpenTC jTSS Wrapper was developed for JRE 1.5 and above. Moreover, unlimited strength encryption has to be enabled in the JRE. For more information refer to: http://java.sun.com/j2se/1.5.0/download.jsp#docs. If you see an error message like **Illegal key size or default parameters** this is an indication that unlimited strength encryption is not enabled on your system.

IAIK jTSS TSP library

Since IAIK/OpenTC jTSS Wrapper and the IAIK jTSS share the same top level API, the IAIK jTSS TSP library is required to use IAIK/OpenTC jTSS Wrapper. IAIK jTSS can be downloaded from http://trustedjava.sf.net/. The IAIK jTSS TSP library (iaik_jtss_tsp.jar) can be found in the `lib` folder. It has to be copied into the `ext_libs` folder of the IAIK/OpenTC jTSS Wrapper.

GCC Toolchain

To compile the native C part of the JNI interface, a C compiler and linker is required. GCC is usually a part of Linux distributions.

SWIG (optional)

If you want to re-create the C and Java (tm) JNI glue code SWIG is required. Note that IAIK/OpenTC jTSS Wrapper already comes with pre-generated JNI glue code. In many cases, SWIG can be installed using the package management of your Linux Distribution.

JUnit (optional)

JUnit is required if you want run the test cases provided with the IAIK/OpenTC jTSS Wrapper package. JUnit can be downloaded from http://www.junit.org/.

4.6.4 Compiling and Installing

This section will guide you through the build and installation process. It covers the TPM Emulator from ETH, the TrouSerS TSS stack and finally the IAIK/OpenTC jTSS Wrapper.

4.6.4.1 Building and Installing the TPM Emulator

If you have a hardware TPM you can skip this step (but you have to make sure that you have a hardware driver installed for your TPM that is compatible with TrouSerS).

- download the sources (v0.5 or above) from: https://developer.berlios.de/projects/tpm-emulator/
- unpack the sources: `tar zxf tpm_emulator-0.5.tar.gz`
- enclosed you will find a README file that describes the next steps
- build and install the TPM emulator according to the README

4.6.4.2 Building and Installing the TrouSerS TSS stack

- download the sources (v0.2.9.0 or v0.2.9.1) from: http://trousers.sourceforge.net/
- Note: this release is not compatible with TrouSerS 0.3.x.
- unpack the sources: `tar zxf trousers-0.2.9.tar.gz`

- enclosed you will find a README file that describes the next steps
- if you use a TPM version 1.2 you need to apply IAIK's TPM 1.2 Patch for TrouSerS 0.2.9 before building. It is available from the http://trustedjava.sf.net/.
- build and install the TrouSerS TSS stack according to the README

4.6.4.3 Building and Installing the IAIK/OpenTC jTSS Wrapper

This section provides a step by step guide of the build process of the "partially prebuilt" version of the IAIK/OpenTC jTSS Wrapper.

unpack the source and change into the source folder `+tar jxf jTssWrapper_0.3.tar.bz2` `+cd jTssWrapper_0.3` customizing the Makefile: Open the Makefile with your favorite text editor and customize the following options:

- `JDK_INC_PATH` has to point to the include folder of your JDK
- `GCC` has to point to your C compiler (typically gcc is already installed on most Linux distributions)
- `LD` has to point to your linker

Now save and close the Makefile.

building the native library with `make`

note: For linking, it is assumed that the libtspi library of TrouSerS is located in a path known to your linker. Otherwise you might want to set the LD_LIBRARY_PATH environment variable accordingly.

Note: you can re-generate the prebuilt swig interface with `make full`.

At this point you should now have a file called `libtspiwrapper.so` in the output/lib folder. For testing the setup, please proceed to the Testing the Setup section below.

4.6.4.4 IAIK jTSS TSP Library

Please ensure that you have downloaded the IAIK jTSS TSP library (see External Requirements). The IAIK jTSS TSP library has to be copied from the `lib` folder of the IAIK jTSS to the `ext_libs` folder of the IAIK/OpenTC jTSS Wrapper.

4.6.4.5 Testing the Setup

The IAIK/OpenTC jTSS Wrapper is shipped together with a set of unit tests which can be found in the `tsp_tests` folder. The unit test come already as a jar. This section describes how to start the individual components to be able to run the unit tests. It is assumed that the TPM emulator is used. If you are using a hardware TPM simply skip the steps involving the emulator.

WARNING: If you are not using the TPM emulator, please note that the jUnit tests include also test code for the TakeOwnership operation where an owner password (for instance "opentc") is set. The TakeOwnership operation will fail if there is already an owner set. It is generally NOT recommended to run the test suite on a TPM that is actually used in a production system with sensitive data protected by the TPM.

Before the unit tests can be run, the TPM emulator Kernel module has to be loaded:

```
modprobe tpmd_dev
```

In the next step start the userspace part of the TPM Emulator:

```
tpmd -f clear
```

Please note, that it might be required to unload TPM hardware drivers loaded by your distribution since they might conflict with your distribution.

After loading the emulator, a new device node `/dev/tpm` should show up. Depending on distribution, you might need to create the following symlink to make the TrouSerS TSS work with the emulator:

```
ln -s /dev/tpm /dev/tpm0
```

As a next step, the Trusted Core Services Daemon tcsd of the TrouSerS TSS has to be started (-f for foreground):

```
tcsd -f
```

The tcsd binary is assumed to be located in the PATH of your shell.

Finally, to start the unit tests change into the IAIK/OpenTC jTSS Wrapper folder and enter the following command:

```
make run_tests
```

This will run the JUnit test suit. If all goes well, the test run should conclude with a statement like: `OK (52 tests)`.

In case you want to clear the persistent storage of the TrouSerS TSS (which might happen from time to time when doing tests and development), you have to delete the following file (default location):

```
/usr/local/var/lib/tpm/system.data
```

4.6.4.6 Summary of components

This section presents a summary of the of the most important parts of the IAIK/OpenTC jTSS Wrapper distribution.

- **src_tsp:** source of the object oriented API
- **src_tsp_test:** JUnit test code
- **output/jars:** JAR archives of the lowlevel JNI classes (iaik_jtss_wrapper_swig.jar), the highlevel object oriented API classes (iaik_jtss_wrapper.jar) and test classes (iaik_jtss_wrapper_test.jar).
- **output/lib:** native library (libtspiwrapper.so)
- **output/javadoc_highlevel:** JavaDoc of the highlevel API

4.7 Documentation and Further Reading

IAIK/OpenTC jTSS Wrapper distribution comes together with a JavaDoc type documentation which can be found in the output/javadoc_highlevel folder.

A good starting point for further reading is the TSS 1.1b specification at http://www.trustedcomputinggroup.org/ where all TSS functions are described. As far as the IAIK/OpenTC jTSS Wrapper is concerned, the relevant parts are the general sections of the document and the parts detailing the Tspi_* functions.

A good place to get started with the IAIK/OpenTC jTSS Wrapper are the JUnit tests provided in the highlevel_tests folder.

4.8 Further Help

This software is provided "as is". However, a mailing list mailto:trustedjava-support@lists.sourceforge.net is maintained at http://trustedjava.sf.net/ to assist users and to allow users to help each other. You are invited to join the discussion, but kindly take a look at the mailing list archive before posting a question.

4.9 Experimental Features

These features are purely experimental, not throughly tested and NO support whatsoever can be provided.

- Experimental support for compilation to native code with GCJ. This can be useful for debugging the JNI interface and the underlying stack with standard tools like GDB or valgrind.
- Experimental support for Infineon's TSS implementation. Note that this stack currently is NOT available to the public.

4.10 Acknowledgments

- Hans Brandl (Infineon) for providing a mainboard with an 1.1b TPM.
- Georg Rankl (Infineon) for answering numerous TPM related questions.
- Kent Yoder (IBM) for discussions and answers regarding the TSS.

4.11 Copyright Notice

The copyright for contents of the IAIK/OpenTC jTSS Wrapper package, including all related documentation, is owned by IAIK, Graz University of Technology.

4.12 Trademarks

Java (tm) and all Java (tm) based marks are a trademark or registered trademark of Sun Microsystems, Inc, in the United States and other countries. All other trademarks and copyrights are property of their respective owners.

4.13 Revision History

Date	Version	Comment
2007/11/28	0.3.1	Synchronized interface with jTSS 0.2, bugfixes, new experimental features.
2007/04/24	0.3	Wrapper now using the same highlevel interface (TSPI) as full jTSS
2007/02/08	0.2.5	Wrapper now compatible with TrouSerS 0.2.9, see the included changelog
2006/09/25	0.2.4	Wrapper now compatible with TrouSerS 0.2.8, see the included changelog
2006/08/25	0.2.3	Wrapper now compatible with Java (tm) 1.3, Loging updated, AIK creation removed, bugfixes, see the included changelog
2006/07/14	0.2.2	adopt AIK creation cycle to work with TCcert 0.2, bugfix and maintenance release, see the included changelog
2006/07/05	0.2.1	AIK cycle with certificates, capability bugfixes, additional TCPA structures for Quotes, see the included changelog
2006/05/30	0.2	Major Restructuring, Bugfixes, Identity Creation TestCase, Hardware Tests, TCPA struct decoder, see the included changelog
2006/02/20	0.1	Initial Release

5 jTSS API Detailed Specification

Note: For reasons of brevity, this chapter, counting over 600 pages, is not included in this version of the text.

6 References

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