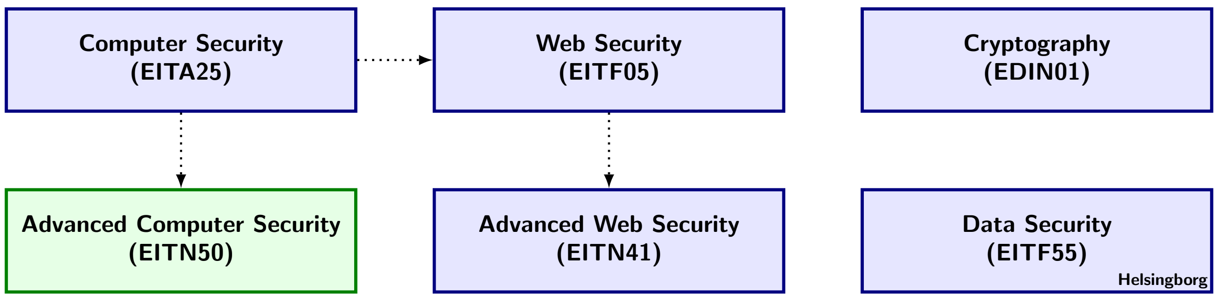
Advanced Computer Security 2021

Department of Electrical and Information Technology
Lund University

Project: TPM

Learning goals:

- Introduce TPM usage concept.
- Understand TPM1.2 key hierarchy.
- Understand binding and sealing, and attestation.
- Understand key migration.
- Write a simple TPM application.


Computer Security (EITA25)
Web Security (EITF05)
Cryptography (EDIN01)
Advanced Computer Security (EITN50)
Advanced Web Security (EITN41)
Data Security (EITF55)
Helsingborg

Version	Comment
2021-09-19	checked links and updated year numbers.
2020-10-21	replaced FMV link.
2020-09-19	checked links and updated year numbers for 2020.
2019-09-24	updated year numbers for 2019.
2018-08-30	preliminary version for 2018.

Table 1: Document version history

Preparations

This project concerns a study of the use of the Trusted Computing Group(TCG) Trusted Platform Module (TPM). Currently, there are two versions of TPMs, the TPM1.2 and the TPM2.0. Although this project concerns TPM12 specifics it also is a general introduction to some of the typical use of TPM functions that also return in the newer TPM20[1].

- Read the course slides,
- Get and glance through the TPM specifications, part1, [7], and part3, [9], (especially the document where the TPM commands are defined). Later you might need to lookup the description of some commands.
- Read the entire project description (this document) before you begin.
- Read the document `http://www.eit.lth.se/fileadmin/eit/courses/eitn50/the_making_of_a_report.pdf` about how to write the report.

If you use the virtual machines TPM1, TPM2 and TSS then there is no need to further configure or install additional software like TrouSerS. Only if you want to run the project in your own environment you may have to install additional software packages.

Instructions for Project Approval

The project consists of a number of assignments that guide your work and you should use the assignment numbers in the answers in your report.

- In the report give clear indications with reference to the related assignment and question numbers when you write down your answers.
- Indicate the version date of this document upon which you base your work an report.
- Document your work with logs and printouts.
- IMPORTANT: Send your report to `ben.smeets.lu@analys.urkund.se` and MARK IT WITH YOUR GROUP NUMBER, add also the name of the group members.
- The first part of the project contains A type assignments and the second part contains the B type assignments that you need to do to qualify for a grade 4.

Document change history

Table 1 shows updates of this document. See to it that you have always the latest. Old versions of this report can be found using the link structure below. `http://www.eit.lth.se/fileadmin/eit/courses/eitn50/Project_TPM/Project_TPM_2019_09_24.pdf`

[1]TPM1.2 uses different ways to authenticate commands; OIAP, OSAP, and DSAP. Although essential, we do not study these as their specifics are no longer present in TPM2.0 which has a much more flexible way to implement command authentication through so-called policies.

1 Introduction

The TPM is a security chip that has been specified by the Trusted Computing Group (TCG) to allow a PC/server platform to implement several security functions that increase the trustworthiness of the (processing) platform. In particular, the TPM provides functions to implement a verified or measured boot, secure remote attestation of platform configuration, and secure storage of sensitive data. When developing software that makes use of the TPM one needs access to TPM functionality. Using here an actual physical TPM, albeit most realistic, is problematic as the TPM has limitations when it comes to bringing it to a pristine state after one has conducted some experiments, it security mechanisms can lock out users, the non-volatile storage has a limited lifespan, and certain operations are limited by the use of so-called localities.

In this project you will use an environment for testing TPM application software with an TPM emulator. This emulator can be easily be completely reset or one can save its state if one later wants to redo a test under the same conditions. The project considers the TPM version 1.2. This version is now being phased out but since it has concepts in common with the newer TPM version 2.0 (short TPM 2.0) and since there are much more mature tool chains freely available the version 1.2 TPM is still the most useful learning vehicle.

The TPM emulator provides an almost accurate functional emulation of the TPM. Of course it responses faster than the real, physical, TPM that has a very slow bus interface and a very constraint processor. The emulated TPM can, like the real TPM, lock itself. That can be rather catastrophic with a real TPM but here we just can remove the file with the TPM state and we can start all over again.

2 TrouSerS

The TCG has specified several APIs to use the TPM. The lowest level of API is formed by the command and response messages that are sent to/back from the TPM. This calls TCG the TCG Device Drivery Library (TDDL). A more convenient API is formed by the TCS API which lifts the low level API into a standard function call API. This API allows users to use all the TPM functions but leaves many details to the user to solve, for example, the handling of the key blobs when they have to be stored outside the TPM. Also some use cases of the TPM, like the use of unbind/bind requires the implementation of functions outside the TPM, in this case the bind operation because the TPM only implements the unbind operation. For that reason there is even a higher level API, the TSP. The combination of TCS, TSP, and driver library TDDL is called the TCG Software Stack, TSS, see Figure 1. A very frequently used implementation of TSS is the open source TrouSerS. In our project we will use TrouSers. TrouSerS supports the use of a real physical TPM, a local emulated TPM or even a remote TPM. We use the latter setup and have the remote TPM as an emulated TPM running on another machine. Here we use a virtual machine or mini system like a Raspberry Pi that we connect via TCP/IP.

TrouSerS has been developed initially by IBM for use under Unix. Although some Windows and Java ports of TrouSerS exist (in part), TrouSerS is a more Unix inclined software stack. Microsoft has developed an own TSS. It has a slightly different setup. Under Windows the TDDL is replaced by a TBS and a TBS.dll[2]. The TCS layer is an adoption of the TCG, see course lecture slides.

Figure 2 shows the setup of your the project environment. Although it is possible to connect to a physical TPM we will only use the TPM emulator. The TPM emulator keeps its internal state into a file `00.permall`. If you want to totally reset the TPM you can just delete this file. The file is in the directory specified by the environment variable `TPM_PATH=/home/pi/tpm/tpm4720/tpmstate`.

[1]This project uses exercise material developed in the Master Thesis "Emulation of TPM on Raspberry Pi" by Marcus Sundberg and Erik Nilsson. [1].

[2]Windows 8.1 and Windows 10 have a TBS.dll that handles TPM version 1.2 and TPM 2.0 and differs from the TBS.dll in Windows 7 and older.

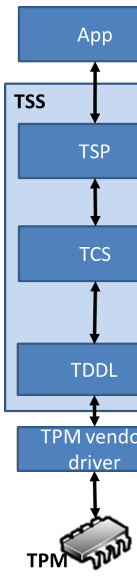


Figure 1: TCG Software Stack (TSS)

3 Project Assignments - Part A

In the project assignments you will try out different TPM functions and at the and write a TPM application that you developed yourself. Reading the TPM specifications and the TrouSerS API description is very useful but since the information is rather overwhelming we take this approach to lead you to the point that you can write an TPM application yourself and have a basic understanding how the TPM V1.2 works.

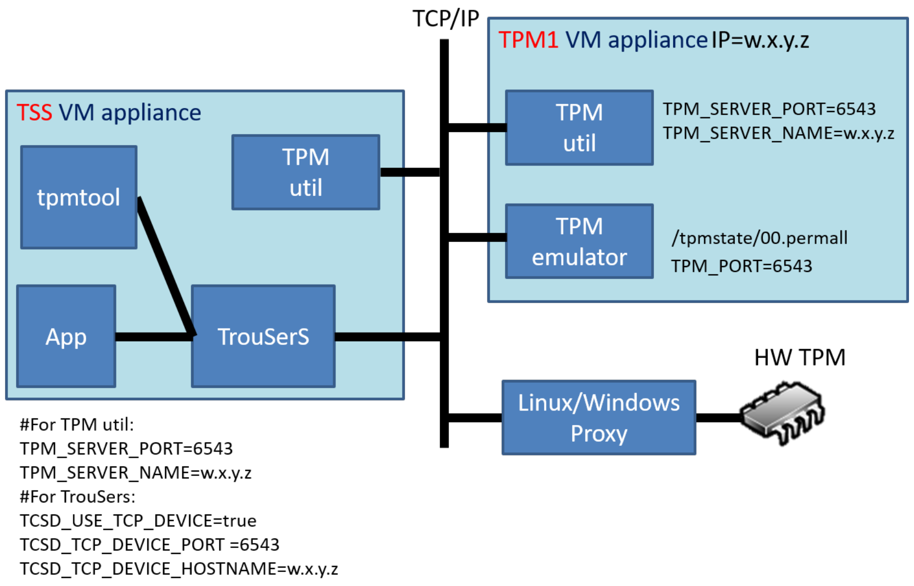
A set of command lines utilities designed to demonstrate various TPM functionality comes bundled with the IBM TPM emulator. These utilities can be used to demonstrate the following functions:

- Key creation
- Key migration
- File encryption
- Authentication
- Attestation

As explained before, to develop an actual TPM application we use the TrouSerS implementation of the TSS Stack. Development of such an application using TrouSerS will be described in the last two (type B) assignments. But before we do that we get you going and we go through some of the basic steps of using the TPM.

3.1 Assignment 1: Setting up the environment

For this project you find three prepared virtual machines called `TSS`, `TPM1`, and `TPM2`. The `TSS` machine is to be seen as an instance of a PC or a server. On this server we use a TPM but in our case this TPM is emulated and not a physical TPM and actually not located on the machine itself. The emulated TPM is found on `TPM1` and `TPM2`. The virtual machines are placed on a virtual network via which they can communicate without being part of the lab computer network. Start machines `TSS` and `TPM1` on your computer using VirtualBox, login on TSS as user ”tss” using password ”lab” and check that you can ping the TPM1 machine which has IP address `10.0.2.14`.



```
TPM_SERVER_PORT=6543
TPM_SERVER_NAME=w.x.y.z
```

```
/tpmstate/00.permall
TPM_PORT=6543
```

```
#For TPM util:
TPM_SERVER_PORT=6543
TPM_SERVER_NAME=w.x.y.z
#For TrouSers:
TCSD_USE_TCP_DEVICE=true
TCSD_TCP_DEVICE_PORT =6543
TCSD_TCP_DEVICE_HOSTNAME=w.x.y.z
```

Figure 2: Experimental setup: you work mainly by using terminal screens on the `TSS` machine.

To login on `TPM1` use the credentials: user "pi" and password "tpm". The second TPM machine `TPM2` you will use a bit later so you can wait with that one until we need it. You can transfer files between the machines using the FileZilla utility.

The `TSS` machine is the client machine on which you do almost all your work!

Both TPMs (on `TPM1` and `TPM2`) are in their pristine or empty state. That is, they do not have an EK key yet and the NVRAM is cleared. The state of the TPM is stored in a file which you can find in the directory

```
/home/pi/tpm/tpm4720/tpmstate
```

You can make manually a copy of this file if you want to save the state in case you want to repeat an experiment when the TPM is in a certain state or you can delete the file if you want to entirely reset the TPM! You will then loose access to any of the keys and data that the TPM protected, so be warned.

To run the TPM emulator the following environment variables must be set

```
TPM_PATH=/home/pi/tpm/tpm4720/tpmstate
TPM_PORT=6545
```

The TPM emulator comes with many utility commands to use the TPM. These commands require the following environment variables to be set using

```
export TPM_SERVER_NAME=localhost
export TPM_SERVER_PORT=6545
```

This should be done already when you open a command window but remember this requirement.

Finally open now two command windows on the TPM machine. In the first window you issue the command

```
tpm_server
```

This starts the TPM emulator. In the second window you can issue the TPM utility commands. In the appendix there is a list of all the utility commands you can use to play around with the

TPM. The utilities that are also installed on the TSS machine.

On the TSS machine you use TrouSerS and this requires you to set `TCSD_USE_TCP_DEVICE`, `TCSD_TCP_DEVICE_PORT` and `TCSD_TCP_DEVICE_HOSTNAME` as well as `TPM_SERVER_NAME`.

```
export TCSD_USE_TCP_DEVICE=true
export TCSD_TCP_DEVICE_PORT=6545 (default port)
export TCSD_TCP_DEVICE_HOSTNAME=10.0.2.15 (the actual IP number of the TPM machine)
export TPM_SERVER_NAME=10.0.2.15 (the actual IP number of the TPM machine)
```

Check these environment variables by entering the `env` command. If necessary, replace the IP address with the actual IP address of the TPM1 machine which you can check via the `ifconfig` command on the TPM machine.

Remark 1: If you want the do ”copy and paste” from the virtual machine and your host, you should enable this feature in the VirtualBox application. Google if needed.[3]

Remark 2: If you want to (re)compile the code of the emulator or the utility programs read the instructions in the appendix section.

3.2 Assignment 2: Getting the TPM ready for use

3.2.1 Introduction

First we have to do a number of basic steps to get the TPM working. The first step is to activate the TPM. A TPM that has been newly installed on the system is normally deactivated. The TPM is activated in the BIOS (which means that the BIOS must be adopted to use the TPM!). The next step is to ensure that the TPM contains an EK key pair and a certificate for the EK. It should be the manufacturer that creates the EK and certificate at manufacturing but unfortunately this is not always the case. If the EK is not created at manufacturing it has to be created and certified as the second step in the TPM provisioning. For our purpose we ignore the EK certificate.

The third step is to take ownership of the TPM. It is in this step where the SRK is created. Two passwords have to be set in this step. One for the owner of the TPM and one for the SRK. The owner password is needed when, for example, the TPM settings are changed and the SRK password is required when the SRK is used to store other keys.

3.2.2 Instructions and Questions

Before we can do anything with the TPM we must be able to send commands to it end receive its responses.

1. An actual hardware TPM is enabled and disabled in the BIOS. Before a connection to the software TPM is made, the BIOS process has to be simulated. This is done by issuing the `tpmbios` command on the `TSS` machine (the search path for executables is already configured to this command). This does a `TPM_Startup`, which is the TPM command used to either deactivate the TPM, start up the TPM with a reset of the PCR registers, or start up the TPM with a restore of PCR values from their saved state [2].

   Note: `tpmbios` has to be reentered (on the TSS machine) every time the TPM emulator is started.

2. Next we establish a connection from the TSS machine to the TPM emulator on machine TPM1 over TCP/IP. Towards this end we start a deamon process on the `TSS` machine by issuing in a command window on its own only for this purpose
   ```
   sudo -E /usr/local/sbin/tcsd -e -f
   ```
   The ”-E” option is important so the environment variables are correctly passed to the sudo environment.

[3]Enable copy and paste video: `https://www.youtube.com/watch?v=_DZbZ3kuzf4`.

3. In the third step the EK keypair will be created. When using the emulator the EK has to be created by the user. This is done by using the utility `createek`. Keep an eye on the TPM emulator terminal when the command `createek` is executed. The EK public key will be printed to the terminal. Take a screen capture of it.
4. The next step is to take ownership of the TPM. This will create the SRK and set a password to the TPM and the SRK. The utility for taking ownership is `takeown -pwdo ooo -pwds sss`, where `ooo` and `sss` are the passwords to the TPM owner and the SRK. These passwords can be set to other values by the user.

   Note: Memorize the passwords as you will needed them later.
5. Which TPM command can be used to obtain the SRK public key in `SRK.pub` format (not PEM!)? Find the command, see appendix, that achieves this and read (public portion of) SRK from the TPM. Hint: handle of the SRK is 40000000.

After these steps the TPM is setup and ready for use.

3.3 Assignment 3: Key hierarchy

3.3.1 Introduction

All keys associated with a TPM are organized in a key hierarchy with the Storage Root Key (SRK) as its root. Keys in the hierarchy are marked as migratable or none-migratable, indicating whether the private portion of the key can be moved between TPMs.

A platform migratable key is usually owned by the system administrator and has the well-known secret for its authorization. It requires the TPM owner's authorization to migrate. If it is migrated, all other migratable keys (which in this design will be children or grandchildren of this key) will also be migrated. After the platform migratable key is loaded, a user can load his base migratable storage key and his base non-migratable storage key because the TPM now knows the private key of the platform migratable key necessary to decrypt the user migratable key.

3.3.2 Questions

1. The identity key is one type of signature key. Describe some differences between an identity and a signature key.
2. Which keys can be used for file encryption?
3. There is one type of key that exists, but its use is not recommended. Which key is that, and why does it exist?

3.3.3 Instructions: Create a key hierarchy

To generate keys you can use the `createkey` and `identity` commands. Issue a key generation command on the command line without any options or arguments and look at the printout. It tells you how the command can be used to generate keys of different types.

Next, create a key hierarchy as specified by the table below:

name	parent	type
A	SRK	non migratable storage key
B	A	migratable storage key
C	B	a non migratable sign key
D	B	a migratable sign key
E	B	a migratable bind key
F	A	a non migratable sign key
G	A	a migratable sign key
H	SRK	an identity key.

Hint: Are all combinations possible? If not, why?

Make a drawing of your key hierarchy and motivate your solution. Look at the utility commands in the appendix section. The keys can be loaded into the TPM by using the command `loadkey`. When loading a key keep track of the key handle the TPM gives to the key.

3.4 Assignment 4: Key Migration

3.4.1 Introduction

By using key migration the user can transfer the migratable keys to another system. This is useful for backups and when the TPM is transferred to another system. If a parent key is migrated all the children of this key are migrated as well. When doing a key migration, a blob is created which is then transferred to the target.

3.4.2 Questions

1. Is it possible for a migratable key to be the parent of a non-migratable key?
2. Which command is the first to be executed when performing a key migration?
3. Give a short description of the command `TPM_ConvertMigrationBlob`.
4. Which TPM command loads the migrated keys into the TPM?
5. Is it the TPM or the TSS that handles the transfer of the migration blob?

Hint: Use the document "TPM Main Part 3 Commands" ([9]) to find more information about the TPM commands.

Migration in TPM1.2 can be realized in various ways. There are procedures by which it is possible to secure that migration only can happen between real TPMs, that is, the private portion of the key is never exposed in cleartext outside the TPM. Since these procedures have been replaced in TPM2.0 we will not study them.

3.4.3 Instructions: Key migration in the TPM emulator

In this assignment we will show how migratable keys can be migrated. We migrate a key from the TPM on machine TPM1 to the TPM on machine TPM2. We use again the emulator demo utilities on the TSS machine.

Now you have to start the virtual machine `TPM2` and prepare it for use. You may have to remove the state of the `TPM2` so you start from a conditions where you know the state of this TPM. Note also the IP address of `TPM2`. We switch between the two TPMs by changing the `TPM_SERVER_NAME` and `TCSD_TCP_DEVICE_HOSTNAME` environment variables, e.g.,

```
export TPM_SERVER_NAME=<TPM2 ipaddress>
export TCSD_TCP_DEVICE_HOSTNAME=<TPM2 ipaddress>
```

On the TSS machine you have to restart the `tcsd` deamon after you modified these two environment variables.

We use the keys and the blobs of Assignment 3, specifically keys A through E. First create a migration key blob on TPM1 for B that can be saved and then reloaded on TPM2. Migrate the keys using the utility `migrate`. Change both environment variables to the TPM2 machine and reload the key on TPM2 using the utility `loadmigrationblob`.

After we migrated key B to TPM2 try to load key C, D, and E into TPM2. Explain what happens (why does it work or not work?).

Hints:[4] Warning: when working with two TPMs it is advised to do that from different directories on the TSS machine. When issuing TPM commands files will be written in the directory from which you issue the commands and it may happen that you overwrite existing files.

```
migrate -hp <parent handle in hex> -pwdp <parent password>
    -pwdo <TPM owner password>
    -hm <handle of migration key> or -im TPM2_STORAGEKEY_FILENAME.key
    -pwdk <TPM2_STORAGEKEY_PASSWORD>
    -pwdm <MIGRATION_PASSWORD of STORAGEKEY>
    -ik STORAGEKEY_FILENAME.key
    -ok migrationblob.bin
loadmigrationblob -hp TPM2_STORAGEKEY_HANDLE -pwdp TPM2_STORAGEKEY_PASSWORD
    -if migrationblob.bin
```

3.4.4 Questions

1. Do the above migration and document in your report.
2. There are other ways to migrate keys. When do you use a key of type `TPM_KEY_USAGE` = `TPM_Migrate` (Hint: look in [8])
3. What is the rewrap option of the `migrate` command used for?

3.5 Assignment 5: Extending values to PCRs

3.5.1 Introduction

The PCRs (Platform Configuration Registers) are used to save SHA-1 hash digests of applications. This capability is used for both trusted boots and attestations. By calculating and recording a digest of an application, it is possible to assess if the application is authentic or not. If one single bit is changed in the application, the hash digest will differ.

3.5.2 Questions

1. Describe one TPM command that can be used to extend a SHA-1 digest to a PCR.
2. Describe which TPM command that can be used to read a PCR value.

3.5.3 Instructions: SHA-1 calculation and PCR extending using the TPM emulator

This assignment will show how a TPM can calculate a SHA-1 digest of an application and then extend this to a PCR. This is done by using the commands:

```
TPM_SHA1Start
TPM_SHA1Update
TPM_SHA1CompleteExtend
```

The first command starts the SHA-1 calculation, and if the file is too large then it passes the remaining calculation to the second command. The last command finishes the calculation and extends the result into a PCR. The demo function that can be used to illustrate these commands is `sha -if <filename> -ix <PCR index>`. Calculate the hash value of, for example, the binary file tpmbios and extend it to the PCR 11. Keep an eye on the TPM emulator terminal. Read the PCR value using the utility `pcrread` when the calculation is done and put in the report.

[4]Because of limitations in the implementation in the migrate commands we cannot migrate a migratable storage key such that SRK becomes its parent.

3.6 Assignment 6: File encryption

There are four commands that handle the encryption and decryption of data in the TPM. Three commands are supported by the TPM: `TPM_UnBind`, `TPM_Seal`, and `TPM_UnSeal`. The fourth command is supported by the TSS, `TSS_Bind`.

3.6.1 Questions

1. Why is `TSS_Bind` a TSS command, and not a TPM command?
2. Give some differences between Data binding and Data sealing.
3. Can a key used for data sealing be migrated to another TPM?

3.6.2 Instructions: Data binding using the TPM emulator

Create a migratable binding key using the command `createkey` on TPM1. Then encrypt a file with some text using the `.pem` file created by `createkey`. The command used for this is `bindfile`. (Note that the key does not have to be loaded into the TPM). Then try to decrypt the file using the command `unbindfile`. Note that the command `loadkey` has to be executed before decryption is possible. Why doesn't the key have to be loaded inside the TPM when encrypting, but it has to be when decrypting?

Now migrate the binding key to TPM2 and see if you can decrypt the file there too. Explain what you observe.

3.6.3 Instructions: Data Sealing using the TPM emulator

Create a storage key and load it into the TPM using the commands `createkey` and `loadkey`. Seal a text file using the storage key with the command `sealfile`. Unseal the file using the command `unseal`. Test if you can do a sealing with a legacy key, a binding key or a signing key. If not, why?

Now migrate the storage key to TPM2 and see if you can unseal the file there too. Explain what you observe.

3.7 Assignment 7: TPM Authentication

3.7.1 Introduction

TPM authentication is used to bring answer to the question "Is this it really TPM X?" we are interacting with and not a hostile system claiming to be a TPM.

Signature based:
The goal of this assignment is to show how a TPM can authenticate itself by digitally signing a file using a signature key, and then letting the target verify the signature using the public part of the signature key pair. If the signature is valid then this proves that the TPM knows the private key of the signature key pair and this proves that the TPM is who he claims to be.

Decryption based:
The goal of this assignment is to show how a TPM can authenticate itself by decrypting a file. If a TPM encrypts a file using its public storage key, then only the user that has the private key portion of the key pair is able to decrypt the file. If a user can decrypt the file, then this user possesses the private key and is therefore the correct user.

3.7.2 Questions

1. In the above, could the `verifyfile` command have been done by another TPM?

2. Which TPM command is used to decrypt the file?
3. Can the decryption based authentication be done by using data sealing instead of binding?

3.7.3 Instructions

Do the following and document in you report.

1. Sign a file with some text in it by loading a signature key into the TPM1 and use this key to sign the file using the utility `signfile`. Let TPM2 verify the signature by using the utility `verifyfile`.
2. Encrypt a file by creating a binding key and load it into the TPM and then encrypt a text file using the command `bindfile` Then decrypt it using the command `unbindfile`.

3.8 Assignment 8: Attestation

Attestation is a mechanism used to obtain a proof that the right software was loaded (by recording its hash in a PCR). The goal of attestation is to prove to a remote party that the loaded application software is authentic and thus trustworthy. This is useful by for example banks who now could ask the user to show that he has the correct versions of the banking software. Just like with authentication, attestation can either be signature based or decryption based.

3.8.1 Signature based attestation

Create an AIK (Attestation Identity Key) using the command `identity`. Use it to quote a PCR value, like the PCR with the hash digest of tpmbios. The verification of the quote will be done automatically. Hints:

```
identity -pwdo <owner password> -la <a label>
    -pwds <SRK password>
    -ok <key filename>
quote -v -hk <key handle in hex> -bm <pcr hash digest> -pwdk <key password>
```

Document the steps in your report. The -v option in the quote command is needed to see the signature since it is not printed on the screen otherwise.

Note: because the bash shell will hijack your quote command you should instead of just `quote` enter the full path of the quote command, i.e. `/home/tss/tpm/tpm4720/libtpm/utils/quote`. .

3.8.2 Decryption-based attestation

With a decryption based attestation we bind a PCR value to a storage key. The key can only be used for decryption if the PCR value that was bound to the key is unchanged or has obtained the same value after a restart of the system. So if a program has been changed, then the PCR value will be different and then the key cannot be used for decryption.

Create a text file and extend the hash digest to a PCR. Create a storage key and bind it to the PCR value using the command `createkey` (-ix is used to specify the PCR index). Load the key into the TPM. Seal the text file using the storage key with the command `sealfile`. Unseal the file using the command `unsealfile` (Should be successful).

Change the text in the text file and extend the PCR with the new hash digest of the text file. Try decrypt the file again (should not work, PCR value bound to the storage key has changed). Clear ownership of the TPM using the command `forceclear`.

Document the steps in your report..

4 Assignments - Part B

4.1 Assignment 9: Your first TPM application

Now you have worked with some of the basic functions it is time to write your own TPM application. You need to use here TrouSerS. Remember that on the `TSS` machine TrouSers is already installed. Recall to have the proper environment variables set.

```
export TCSD_USE_TCP_DEVICE=true
export TCSD_TCP_DEVICE_PORT=6545 (default port)
export TCSD_TCP_DEVICE_HOSTNAME=10.0.2.15 (replace with the actual IP number)
```

You have to clear TPM1 on the machine `TPM1`. Simply stop the tpmserver program, remove the `00.permall` file and restart tpmserver. Do not forget on TSS to issue the `tpmbios` and `createek` commands to initialize TPM and generate the EK. This puts TPM1 in a well-defined state.

Take command of the TPM using `tpm_tools` by writing `tpm_takeownership -z -y` in the terminal. Use the examples found in the section ”Developing TPM applications” and write your own TPM application. For example generate random numbers using `Tspi_TPM_GetRandom` or the value in a PCR using `Tspi_TPM_PCRRead`.

Note1: Instead of brutally clearing the TPM you can also use the following sequence.

```
forceclear
tpm_setenable -e -f
```

After that you can run the `tpm_takeownership -y -z` command.

Note2: In case you do not have experience writing C code you find in Section 4.3 a small code snippet to print an array of BYTES.

4.2 Assignment 10: Programmed setup of SRK

In the first part we used the command line to interact with the TPM and created an SRK. In this assignment you have to create the endorsement key and SRK programmatically using an application that you write. Expand the code of your first applications so it will create the EK and an SRK. Make printouts of the public key values of these two keys using the following hexdump routine that writes to you screen.

4.3 C code to dump bytes in hexadecimal

The following C code might come handy

```
/* routine to print a buffer
*  Use: Printhex(null, buf, 16); or Printhex("Test buffer:\n", testbuffer, 20);
*  sometimes you need to typecast the variable for buffer input (which must be a pointer),
*  e.g. char* yourbuf[10]; Printhex(null, (BYTES*) yourbuf, 10)
*/
void Printhex(char* string, BYTES* buffer, int buf_len){
  char* p = (char*) buffer;
  if (string) printf("%s", string);
  for (int i= 0; i<buf_len;i++){
      if ((i>0) && ((i%16)==0)) printf("\n");
      printf("%2.2x",p[i]);
  }
};
```

References

[1] Sundberg Marcus, Nilsson, Erik, Emulation of TPM on Raspberry Pi, MSc Thesis Lund University, December 2014.

[2] Challener David,Yoder Kent,Catherman Ryan,Sanord David, Van Doorn Leendert. A practical guide to trusted computing, IBM Press, Jan 2008, page 63.

[3] Challener David,Yoder Kent,Catherman Ryan,Sanord David, Van Doorn Leendert. A practical guide to trusted computing, IBM Press, Jan 2008, page 79.

[4] Challener David,Yoder Kent,Catherman Ryan,Sanord David, Van Doorn Leendert. A practical guide to trusted computing, IBM Press, Jan 2008, page 81.

[5] Challener David,Yoder Kent,Catherman Ryan,Sanord David, Van Doorn Leendert. A practical guide to trusted computing, IBM Press, Jan 2008, page 304.

[6] IBM software tpm at sourceforge. http://sourceforge.net/projects/ibmswtpm/.

[7] Part 1 - Design Principles, TPM Main Specification Level 2 Version 1.2, Revision 116

[8] Part 2 - Structures of the TPM, TPM Main Specification Level 2 Version 1.2, Revision 116

[9] Part 3 - Commands, TPM Main Specification Level 2 Version 1.2, Revision 116

[10] Challener, David. An introduction to programming the tpm. `https://docplayer.net/39934873-An-introduction-to-programming-the-tpm.html`

[11] TCG. Tss_1_2_errata_a-final.pdf page 182.

[12] TCG. Tss_1_2_errata_a-final.pdf page 191.

[13] TCG. Tss_1_2_errata_a-final.pdf page 232.

5 Developing TPM applications

5.1 Sample code

As mentioned before when developing TPM application, ones uses normally the TSS library. For TPM1.2 TCG has released a specification of the TSS and a package with C header files. It is however up to each vendor to develop their own TSS. One TSS that is free and open source is TrouSerS as mentioned before. When writing TPM applications on a high level the TSP layer in the TSS architecture is used. This will provide a useful API for easy TPM programming and make the application responsible for key management, memory usage and error handling. A simple TrouSerS application typically is given in Listing 1 and can be downloaded via this link `http://www.eit.lth.se/fileadmin/eit/courses/eitn50/Project_TPM/sample.c`.

5.2 The basic TSPI commands

These are the basic steps that are needed to issue commands to the TPM. It requires the TSPI commands:

`Tspi_Context_Create`: This command tells the TSP to generate a new context handle for the application. This command must be used since there can be more TPM application running on the same machine, so this context is used by TSP to keep track of each application. It also provides functions for resource management and freeing of memory. The handle to the created context object is saved in `TSS_HCONTEXT_hContext` [11], [3].

`Tspi_Context_Connect`: This command connects the TSP context to a TCS provider. The local TCS is represented by Null as seen in the code. If the TPM is not activated on the system then this command will return `TSS_E_NO_CONNECTION`. If the TPM is not activated then

Listing 1: A simple template for a TPM app [2] .

```
#include<stdio.h>
#include<string.h>
#include<stdlib.h>
#include<sys/stat.h>
#include<sys/types.h>
#include<tss/platform.h>
#include<tss/tss_defines.h>
#include<tss/tss_typedef.h>
#include<tss/tss_structs.h>
#include<tss/tspi.h>
#include<trousers/trousers.h>
#include<tss/tss_error.h>
#define DEBUG 1
// Macro for debug messages
#define DBG(message, tResult) { if(DEBUG) printf("(Line%d, %s) %s
returned 0x%08x. %s.\n",\
    __LINE__ ,__func__ , message, tResult,\
    (char *)Trspi_Error_String(tResult));}
// MAIN entry point
int main(int argc, char **argv)
{
    TSS_HCONTEXT hContext=0;
    TSS_HTPM hTPM = 0;
    TSS_RESULT result;
    TSS_HKEY hSRK = 0;
    TSS_HPOLICY hSRKPolicy=0;
    TSS_UUID SRK_UUID = TSS_UUID_SRK;
    // By default the SRK secret is 20 zero bytes
    // takeownership -z
    BYTE wks[20];
    memset(wks,0,20);
    // At the beginning
    // Create context and get tpm handle
    result =Tspi_Context_Create(&hContext);
    DBG("Create a context\n", result);
    result=Tspi_Context_Connect(hContext, NULL);
    DBG("Connect to TPM\n", result);
    result=Tspi_Context_GetTpmObject(hContext, &hTPM);
    DBG("Get TPM handle\n", result);
    // Get SRK handle
    // This operation need SRK secret when you takeownership
    // if takeownership -z the SRK is wks by default
    result=Tspi_Context_LoadKeyByUUID(
        hContext,
        TSS_PS_TYPE_SYSTEM,
        SRK_UUID,
        &hSRK
        );
    DBG("Get SRK handle\n", result);
    result=Tspi_GetPolicyObject(hSRK, TSS_POLICY_USAGE, &hSRKPolicy);
    DBG("Get SRK Policy\n", result);
    result=Tspi_Policy_SetSecret(hSRKPolicy,TSS_SECRET_MODE_SHA1,20, wks);
    DBG("Tspi_Policy_SetSecret\n", result);
    // INSERT TPM COMMANDS HERE:
    ...
    // END OF APP
    // Free memory
    result = Tspi_Context_FreeMemory(hContext, NULL);
    DBG("Tspi Context Free Memory\n", result);
    result = Tspi_Context_Close(hContext);
    DBG("Tspi Context Close\n", result);
    return 0;
```

it is recommended to end the program after this command and activate the TPM before executing again [11], [4].

`Tspi_Context_GetTpmObject`: After a TCS connection is made in the command `Tspi_Context_Connect`, then this command is used to retrieve a handle to the TPM object [4].

`Tspi_Context_LoadKeyByUUID`: This command creates an object of a key and loads it into the TPM. All information about the key is handled by the TCS. In the initial step the SRK is loaded into the TPM with this command.

`Tspi_GetPolicyObject`: This command is used to locate the current authorization policy associated with the context [5].

`Tspi_Policy_SetSecret`: This command is used to create a policy object of the authorization data (owner password), and returns a handle for this object [13].

Note in particular the policy commands and policy objects. They are essential. When the TPM is initialised the user may test its functionality by running for example:
`Tspi_TPM_GetRandom`, which returns a random number of a specified size. Freeing allocated memory is done with the command: `Tspi_Context_FreeMemory` Last command to be used is the command that closes the context: `Tspi_Context_Close` The TPM application can easily be compiled with GCC. The command is [4]:
`gcc -o trousersApp trousersApp.c -ltspi -Wall`
This gives you the executable `trousersApp`.

5.3 Install TPM software

This section is only for those that want to do their project in their own environment instead of using the TPM1, TPM2, and TSS virtual machines. If you use the TPM1, TPM2, and TSS virtual machines you do not have to install any additional TPM software; all is present.

In order to build and install the Software TPM by IBM in the TPM machine, there is a build script to automate the process. See Section 4.4. There are two parameters the user can configure. The default setting are

```
#version
export TPM_V=tpm4720
#install path
export TPM_INSTALL_PATH=/...
```

In order to build the Software TPM, some packages need to be installed on the TPM system: `libtool`, `automake`, `libssl-dev`, `openssl`. [5]. These are already installed on both machines. Now simply run `build.sh` in a terminal shell. The build script compiles the Software TPM at the defined location of choice (if you have the the permission to write at the location of course).

Many distributions support TrouSerS and tpmtools so they can easily be installed then. For Debian based distributions use:

```
sudo apt-get install trousers
```

However it is not difficult to built them yourself. Download TrouSerS from SourceForge. Build and install it with the following commands:

```
sh bootstrap.sh
configure {enable-debug
make
sudo make install
```

When setting up TrouSerS, the first step is to add the line:

[5]Run sudo apt-get install libtool automake libssl-dev openssl in a terminal shell.

```
remote_ops = seal,unseal,registerkey,unregisterkey,loadkey,
createkey,sign,random,getcapability,unbind,quote,readpubek,
getregisteredkeybypublicinfo,getpubkey,selftest
```

in `/usr/local/etc/tcsd.conf`

Next step is to initialise the environment variables. Since TrouSerS will communicate with the TPM over TCP. Check that the following environment variables are set (use of TPM1)

```
export TCSD_USE_TCP_DEVICE=true
export TCSD_TCP_DEVICE_PORT=6545 (default port)
export TCSD_TCP_DEVICE_HOSTNAME=10.0.2.15 (replace with the actual IP number)
```

However in the TrouSers version 1.333 there is a bug which blocks the remote access of TrouSers via IP. Also not all TPM commands are possible. The course web there is a version of the file that should be used instead so you should replace the original one with this file before you compile and install or you just issue make again and do sudo make install after you replaced the file.

5.4 IBM emulator install shell

```
#!/bin/bash
# required stuff
#apt-get install libtool automake libssl-dev openssl
# versions
export TPM_V=tpm4720
# install path
export TPM_INSTALL_PATH=/...
cd $TPM_INSTALL_PATH
mkdir $TPM_V
cd $TPM_V
# download and extract
wget -c http://downloads.sourceforge.net/project/ibmswtpm/$TPM_V.tar.gz
tar -zxvf $TPM_V.tar.gz
# build
cd tpm
make --file=makefile-ts
cd ../libtpm
./autogen
./configure
make
# clean up
cd ..
find . -name "*.o" -type f -delete
```

6 TPM emulator utility commands

There are to sets of utility commands. One set comes with the TPM emulator and the second comes with the tpm-tool package. The commands from the emulator we only use in the beginning. The tpm-tool commands use the TrourSers library and thus TrouSerS must be setup.

Note: For most of the utility commands below you get an explanation how to use the command if you enter the command without any options or arguments.

1. bindfile
2. certifykey
3. certifyselftest
4. chgauth
5. chgtpmauth
6. clearown
7. cmk_approvema
8. cmk_loadmigrationblob
9. cmk_migrate
10. counter_read
11. counter_release
12. createek
13. createkey
14. createkeydelegation
15. createownerdelegation
16. createrevek
17. delegatemanage
18. delegatereadtable
19. dirread
20. dirwrite
21. disablepubek
22. dumpkey
23. enableaudit
24. extend
25. getauditdigest
26. getauditdigestsigned
27. getpubek
28. getpubkey
29. identity
30. listkeys
31. loadkey
32. loadmanumaintpub
33. loadmigrationblob
34. loadownerdelegation
35. migrate
36. migratekey
37. modules
38. nv
39. nv_readvalue
40. nv_writevalue
41. ownerreadinternalpub
42. ownersetdisable
43. quote
44. quote2
45. random
46. readmanumaintpub
47. resetestbit
48. revtrust
49. savestate
50. sealfile
51. sealfile2
52. sealxfile
53. selftest
54. session
55. setoperatorauth
56. setownerinstall
57. setownerpointer
58. sha
59. sha1parts
60. sha1start
61. signfile
62. signmsg
63. takeown
64. tpmbios
65. tpminit
66. tpmreset
67. transport_test
68. unbindfile
69. unsealfile
70. unsealxfile
71. verifydelegation
72. verifyfile

The tpm-tool package provides the following TPM Management Commands:

1. tpm_changeownerauth
2. tpm_clear
3. tpm_createek
4. tpm_getpubek
5. tpm_restrictpubek
6. tpm_selftest
7. tpm_setactive
8. tpm_setclearable
9. tpm_setenable
10. tpm_setownable
11. tpm_setpresence
12. tpm_takeownership
13. tpm_version

We use only `tpm_takeownership` and `tpm_version`.

7 Location of the VM images

The originals of the VM images `TSS`, `TPM1`, and `TPM2` can be found as zipped files on the course disk which should be mounted as `S:` on a lab computer in the `Project - TPM` directory. Copy the images from there to your (lab) machine, unpack them in an directory of your choice from which you want VirtualBox to load the images. Remember that VirtualBox will store the data in the directory that sort of reflects the state of the VM machine. Also snapshots are placed there.

The images can also be downloaded via Canvas `https://canvas.education.lu.se/courses/13677/pages/vm-and-image-downloads`

WARNING: After your done with the project you should remove the images. Note that storing an image on the desktop makes it a part of your profile and thus, due to the size, will cause an increase in your login time if the profile is not present on the machine you login.