
MOBILE DATA SECURITY AND CLOUD STORAGE

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Abstract

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Chapter 1

Introduction

1.1 Motivation

In today's society the standard commercial smartphone is considered secure by the average user. This statement is partially true as the regular user rarely encounters sensitive data apart from personal passwords. As the development on smartphones have skyrocketed new parties have expressed interest in smartphone capabilities. In relation to this there is now a need for the smartphone to handle sensitive data, e.g, health data, military intelligence and governmental information.

Handling sensitive data in context of smartphones involves storing the data, processing the data and potentially sharing the data. In these areas there exists obstacles that need to be dealt with in order to handle the sensitive data securely. Two of the biggest obstacles are being able to encrypt and decrypt data effectively and key management/storage.

1.2 Problem statement

1.3 Goals

The overall goal of this thesis is to explore and evaluate the possibilities of how smart cards and mobile devices can co-operate to achieve a higher level of information security. To better understand what limitations there are, we

will need to create a framework for easy communication between a mobile device and smart card. This includes developing test applications for both the mobile device and the smart card. A framework, mobile application and smart card application allows us to test performance and security, with as close to real life use cases as possible.

To achieve the overall goal we will need to look into a set of sub-goals. The sub-goals are as follows:

1. Determine limitations on the smart card.
2. Identify use cases we are able to solve using smart cards.
3. Outline standards for solving use cases using smart cards.
4. Test the use cases with real-life data.

1.4 Chapter introduction

Chapter 2

Background

In this chapter we will provide background information necessary to understand how smart cards function and can increase security on mobile devices. The topics covered in this section are smart cards, mobile device operating systems, cryptography and threats in context of mobile devices.

2.1 Terminology

APDU Application Protocol Data Unit describes the format of how a smart card and other applications should communicate. Refer to section 2.2.2.

Extended APDU Extended Application Protocol Data Unit is an extension of an Application Protocol Data Unit where the payload data supports lengths up to 65535 bytes.

SELECT APDU SELECT APDU is a type of APDU that has the sole purpose of activating the correct application on the smart card.

Application Identifier (AID)

2.2 Smart Card

A smart card refers to a pocket sized card with an integrated circuit, usually in the form of a plastic card with an integrated micro processor. In essence a smart card is a miniature computer with limited computing power.

2.2.1 Smart card architecture

The micro processor is able to perform tasks that involve processing input, give output and storing small amounts of data. Smart cards vary in sizes defined by the standards ISO/IEC 7810 [16] and ISO/IEC 7816 [17]. The processing power of smart cards are between 25-32 MHz and sport anywhere from 8Kbit to 128Kbit memory (EEPROM) [27].

The micro processor can be powered and communicate in two ways. Contact smart cards have integrated contact pads. When the smart card is inserted into a card reader the contact pads of the card reader provides power to the micro processor via the contact pads of the smart card. The contact pads also works as a medium for transferring data. Contactless smart cards uses radio-frequency induction to power the micro processor and to transmit data between an antenna and the card. Most modern cards support both of these technologies. Figure 2.1 is a blank hybrid card.

An everyday example of a smart card is the modern credit and debit card. Most of these cards are contact cards that require the user to insert the card into a card reader, but newer cards are of the hybrid type, that have the ability to communicate over radio frequencies. Credit and debit cards utilizes the input/output capabilities of the smart card, but they also store information on the card authenticating the users bank information.

2.2.2 Communication standard for smart cards

Application Protocol Data Unit (APDU) is a standard that describes how a smart card application should communicate with other applications (off-card) and is defined by ISO7816-4 [15]. There are two types of APDU messages: Command APDU and Response APDU.

Command APDU is split into header and body. Refer to table 2.1 for instruction explanation and summary. The header is mandatory for all

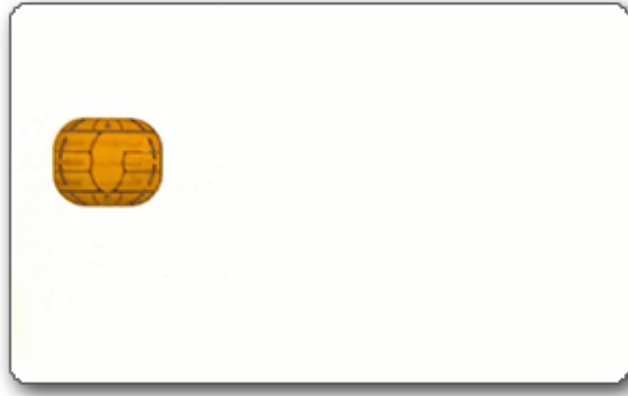


Figure 2.1: Hybrid Smart card.

transactions and consists of 4 bytes that is split into CLA, INS, P1 and P2. The body of a command APDU is split into 3 parts; LC, Payload and LE. LC is 1 byte, payload is maximum 255 bytes and LE is 1 byte.

Newer smart cards supports Extended APDU which allows the payload to be up to a maximum of 65535 bytes. If the payload data is greater than 255 bytes LC must be 3 bytes where the first byte is 0x00 to denote that the APDU is extended and the remaining bytes denotes the length. If extended APDU is used then LE consists of 2 bytes to account for longer responses.

Name	Number of bytes	Description
CLA	1	Command type class, type of command
INS	1	Instruction code, command to run
P1	1	Free parameter
P2	1	Free parameter
LC	0, 1 or 3	Length of payload
Payload	0 - 65535	Payload data
LE	0, 1, 2 or 3	Expected response length

Table 2.1: Command APDU layout.

Response APDU is split into body and response trailer. The body consist

of the response data and is at maximum 255 bytes or 65535 bytes depending on if extended APDU is used. All response APDUs must contain a response trailer of two bytes which denotes the processing status (error, success, wrong format, etc.) of the command APDU. Refer to table 2.2 for definitions and summary.

Name	Number of bytes	Description
Response	0-65535	Response data
SW1+SW2	2	Command processing status

Table 2.2: Response APDU layout.

To better understand when to use the command APDUs and when to use response APDUs we will describe the following example: A locked door has a card reader connected to it. A person walks up to the door and holds up his contactless smart card to the reader. The card reader sends a command APDU to the card asking for the ID. The smart card processes the command APDU and sends a response APDU back to the card reader containing the ID of the person. This example is visualized by figure 2.2.

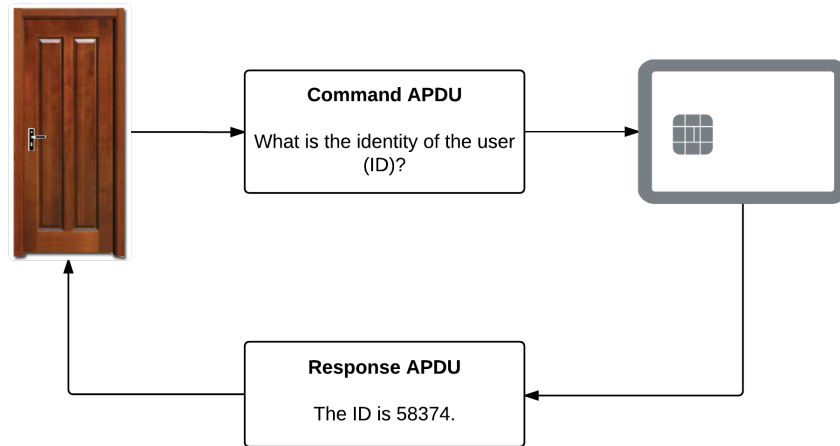


Figure 2.2: Door lock using smart card to unlock.

2.2.3 JavaCard programming language

In section 2.2 we described that smart cards are able to store data as well as process input and output. All smart cards have their own operating system that allows developers to write applications that run on the smart cards. Smart cards are not limited to one applications per card, but are able to have multiple applications installed. Traditionally it was not feasible to create programs that ran on different smart card manufacturer cards as the micro processors were manufacturer specific [33]. This created an environment where smart card issuers and their developers were locked to a specific manufacturer.

The company Schlumberger [25], later joined by Sun Microsystems [21], outlined Java Card 1.0. Java Card were to alleviate the problem of manufacturer specific code and to let developers write generic applications. Newer Java Card version includes a development kit that provides a test environment and a converter tool that prepares the Java Card applet/program for installation onto a smart card. The newest Java Card version is currently 3.0.5 [18].

The Java Card language behaves very similar to standard Java, but there are some substantial differences. Many Java classes and features are not present, e.g., `int`, `double`, `long`, `java.lang.SecurityManager`, `threading` and `object cloning` [3]. The structure of the applets differ from standard Java applets. All Java Card applets must implement:

- `void install (byte [] barray, short bOffset, byte bLength)`
- `void process(APDU apdu).`

Install is invoked when the applet is downloaded onto the smart card and should register and initialize the applet [34]. **Process** is the entry point for all requests to the application and where the applet specific logic is done [35].

When incorporating the features of a smart card with a mobile device it would be beneficial to not rely on an external contact card or contactless card. One of the key features of the Java Card language is that the software is able to run on technological different smart cards. As such it is possible to deploy the Java Card applet to special micro SD memory cards. This essentially enables the smart card to be integrated with the mobile device, but at the same time be an external runtime environment. Figure 2.3 is a micro SD memory card produced by Gemalto.



Figure 2.3: Micro SD card from Gemalto.

2.2.4 Other smart card programming languages

There exists several other languages for smart card programming. The two most notable are JavaCard (section 2.2.3) and MULTOS [20]. The latter uses the programming language C as the language for writing applications.

2.3 Mobile operating system

Mobile operating system refers to the operating system running on a mobile device (smartphones, GPS devices, tablets, etc). In this thesis we will focus mainly on smartphones and tablets since their capabilities are within our scope and the fact that they often share the same operating system.

2.3.1 Android

Android is an open source licensed mobile operating system and is based on one of the LTS (long-term support) branches of the Linux kernel. Google inc. [2] is the current developer of the mobile operating system and their primary focus has been smartphones and tablets. In later years Google has put resources into incorporating Android with TVs, wrist watches and cars. In 2015 Q2 82,8 % of smartphones worldwide was shipped with a version of the Android mobile operating system [28].

The Android mobile operating system supports applications that are written in Java, GO and C/C++. The applications run in their own sandbox with their own allocated memory space, but applications can also access shared resources given permission to do so by the user.

2.4 Cryptography

Cryptography is a method for protecting confidential data using complex mathematics and computer science. Most cryptographic functions/algorithms relies heavily on the fact that the mathematics are so complex that they are "uncrackable" without knowledge of the encryption/decryption key.

2.4.1 Public-key cryptography

Public-key cryptography refers to a set of methods for asymmetric cryptography. It is based around the concept that one entity (user, server, etc.) generates a key pair consisting of one public key and one private key. Data encrypted using the public key can only be decrypted by the private key and due to the complexity of the keys it is improbable that the private key can be generated from the public key. The public key, as the name suggests, is publicly available for other entities. This combination allows entities to communicate securely given that they have each others public key and their private key is stored securely. Figure 2.4 shows how a sender can send a message that only the receiver can read. Although it is important to note that this operation is more resource intensive and time consuming compared to symmetric key encryption/decryption.

Message authentication can also be done by public-key cryptography. First the message is hashed using a secure hash function, for instance SHA-2 [23], which creates a digest. The digest is then encrypted with the private key and the "digital signature" is then sent with the original message. The receiver can then verify the integrity of the message by computing the hash of the message using the same secure hash function and decrypt the "digital signature" using the senders public key. If they are a match the message the receiver can with certainty conclude that the message has not been tampered with and originates from the sender.

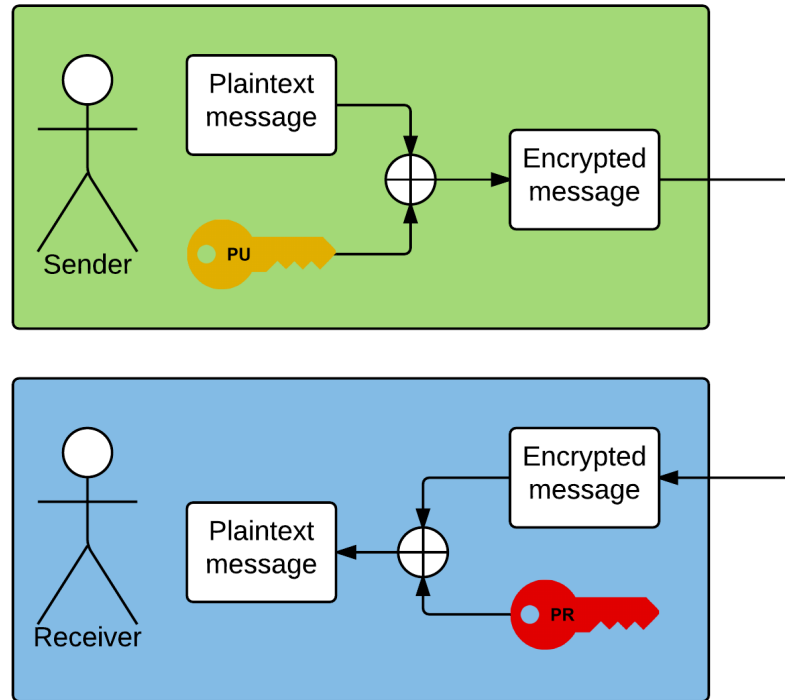


Figure 2.4: Asymmetric key encryption/decryption using public-private key pair.

2.4.2 Symmetric-key cryptography

Symmetric-key cryptography uses the same cryptographic key for both encryption and decryption. There are two main areas of application for symmetric-key cryptography; secure storage of data and secure communication. +Secure storage of data is the most straight forward of the two. An entity (user, server, etc.) generates a key, encrypts the data using the key, stores the key for future use and decrypts the data using the key whenever the entity require the data. As long as the key is stored securely and the encryption algorithm is secure the data can be stored in an unsecured environment. Secure communication using symmetric-key is very similar, but instead of the same entity decrypting the data the encrypted data is transmitted to a new entity which decrypts it using the same key. This requires the key or key

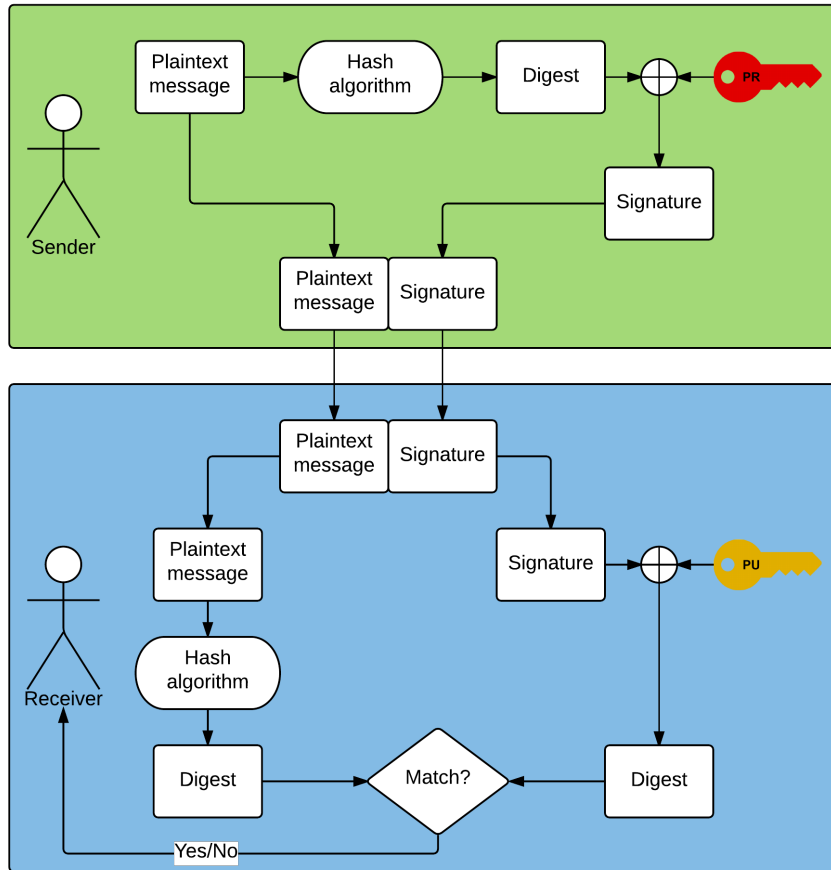


Figure 2.5: Digital signing using public-private key pair.

generation to be a known by both parties, also known as a "shared secret". There are two methods for symmetric-key encryption/decryption. Stream ciphering takes one byte at the time and encrypts/decrypts it whereas block ciphering takes bigger chunks of data and encrypts/decrypts the data. Both methods have their own weaknesses and strenghts.

Stream ciphering is fast and relatively simplistic to implement. This along with the fact that it can encrypt byte by byte makes it very suitable for use when plaintext data comes in unknown length and over time (streams). Areas of application includes voice chat, video feed and http communication. Disadvantages of stream ciphering is that if the algorithm is cracked then

it is susceptible to insertions and modifications as well as the fact that a single plaintext symbol is represented as a single ciphertext symbol (limited alteration).

Block cipher is a more complex and requires more overhead. First of data must be divided into equal size blocks. The blocks cannot be too small as then they are prone to dictionary attacks and not too big as it will make the encryption/decryption process too resource intensive. In block cipher the block size must be fixed through the encryption process. This will often result in redundant data. For example, 200-bit plaintext with a 64-bit block size will result in three blocks of 64-bit and a fourth block with only 8 bit of "real" data and 56 bit of redundant bits. Since block ciphering uses the previous block to cipher the current block it is possible to detect tampering and faults, but this also results that data may be lost if a block becomes corrupt.

2.5 Mobile threats

Mobile threats and attack vectors are numerous and before looking into how smart cards can help mitigate and alleviate threats we will need to identify and characterize them.

2.5.1 Infected device

The most obvious threat to mobile devices is when the mobile device itself is infected with virus or malware. The type of virus or malware can vary, some are harmless and serve more as an annoyance or trying to trick the user into visiting bogus websites, but some are more malicious and will access private files and information. From a security stand-point it is a disaster if a virus or malware is able to read and modify data which is otherwise confidential.

Often the user will not know that their mobile device is infected and some viruses or malware are very hard to detect by anti-virus. The "2015 Cheetah Mobile Security Report" [1] reports that the number of viruses on Android devices exceeds over 9,5 million and that the problem is growing. Taking into consideration that the mobile device we are operating on may be infected is of the utmost importance when designing and developing applications.

2.5.2 Lost or stolen device

An attacker may gain physical access to the users mobile device through theft or simply that the user misplaced the mobile device. With physical access to the device an attacker would be able to retrieve data from the device. A common defence against this is encrypting the data on the device, but this requires the keys to be stored somewhere securely. If the keys are not stored securely the result is that the data on the device will fall into the wrong hands.

2.5.3 Unsecure communication channel

Communication is a vital part of modern systems; data is sent between devices and between devices and servers. Sensitive data requires a secure communication channel which cannot be tapped into by a third party. Secure communication on public networks involves agreeing upon encryption keys which the data should be encrypted with before being sent. Encrypting the communication channel will protect against man-in-the-middle attacks, but this requires both parties to authenticate themselves as encrypting the data won't help if you are sending the data directly to the attacker. More on this in section 2.5.4.

2.5.4 Authentication challenges

As mentioned in section 2.5.3 a secure communication channel is useless if you are sending the data directly to the attacker. A vital part of security is being able to authenticate the parties in a transaction. If the attacker is able to impersonate another party by installing fake certificates on the mobile device or by tricking the user into communicating with the attacker the consequences can be of significance.

2.5.5 Unsecure applications

An often overlooked attack vector is badly implemented applications on the mobile device. This may include memory leaks, weak cryptography, open for code injections and plainly exposing private data to third parties. In rare cases an application with flaws may expose other applications for attacks,

but there exists countermeasures to this, for instance that all applications run in their own sandbox.

Chapter 3

Challenges

In this chapter we will examine what challenges there are with regards to mobile devices and smart cards co-operating. The challenges must be viewed from a use case perspective where the benefits does not come from solving the challenges, but rather what we are able to achieve afterwards. For each challenge we will provide problem description, motivation, key concepts, possible solution and describe possible attack vectors.

3.1 Binding card and phone

3.1.1 Problem Description

One of the key challenges when utilizing smart cards with mobile devices is establishing an initial trust relationship. How can the mobile device know that it communicates with a certified smart card (company/department issued) and how can the smart card know that it is interacting with a trusted user on a mobile device? The biggest problem of the binding process is that the smart card must trust the mobile device, as we have no way of knowing if we are binding to a compromised mobile device. If the mobile device is not initially compromised and we are able to use the smart card as a bootstrap for trust, then the direct result is that we can use smart cards as a policy enforcement point (PEP) and secure key storage/generation. To initialize this trust relationship we need to perform a handshake where we verify that all concerning parties can authenticate and authorize each other.

3.1.2 Goal

By binding the smart card and phone together we wish to ensure that a smart card can only be paired with one mobile device and that we are in full control during the process. If we achieve this the direct consequences are:

- The keys stored on the smart card cannot be retrieved or be used on a different mobile device.
- Our application on the mobile device cannot be used without the smart card that was paired with our mobile device.
- If the binding is successful we may be able to detect if the mobile device becomes compromised on a later point and react to it (delete keys on card, block communication, etc.).

This will mitigate threats such as:

- Lost or stolen device.
- Unsecure communication channels.
- Authentication challenges.

3.1.3 Key concepts

To authenticate the two parties, smart card and mobile device, we will need a third party which they both trust. We introduce a new party, the authority, which acts as the third party. The authority issues the smart cards and employ the users. A direct consequence is that they both trust the authority, otherwise we have no starting point. Since they both trust the authority they can ask the authority to verify the other party as shown in figure 3.1.

One thing that differentiates our problem from traditional authentication problems is that the smart card is not able to communicate directly with a trusted third party. All communication with off card applications or third parties must go through a mobile device. A technical illustration of this relationship can be seen in figure 3.2 where the authority is represented as a server. This drawback introduces a new problem which we have to consider. How do we know if the mobile device relays information between the server and smart card correctly in the authentication process?

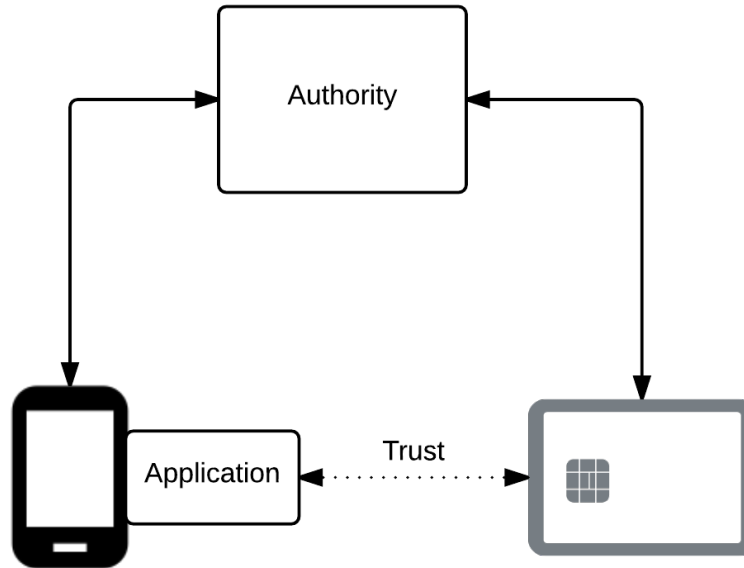


Figure 3.1: Trust based on a third party.

To combat that all information flowing from the smart card has to go through the mobile device, we can utilize the fact that the authority we are trying to authenticate with is also the smart card issuer. What this means is that we can pre-install the authority certificate and public key on the smart card as well as retrieve the public key of the smart card before handing the smart card to the user/employee. The result is that we have already exchanged the keys and certificates we need for authentication before we introduce the mobile device.

The mobile device will also need to authenticate with the authority so that the smart card can trust the mobile device. In this process we will need to make some assumptions. The first problem is that we need to ensure that the mobile device tries to communicate with the right server (authority). By hardcoding the server URL in the mobile device application and making sure that the user installs the right application on his device we can mitigate this threat. To make sure that the user installs the right application we need a secure distribution platform. By using Google Play as distribution platform, we can minimize the risk that the user will download a rogue application

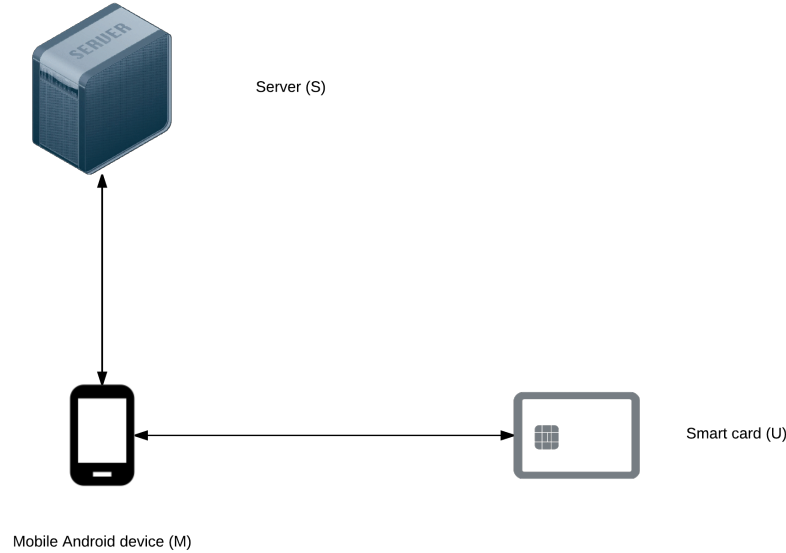


Figure 3.2: Server, mobile device and smart card communication flow.

with the same name [22]. To further mitigate the risk of installing the wrong application the user can disable the ability to side-load applications and not use a rooted device.

The other attack vector on the mobile device and user is man-in-the-middle attacks. If we assume that the user was able to download the correct application we will need to secure the communication channel. To secure the channel we will need to use TLS [32] which also provides us with protection from replay attacks [7]. The only downside by using TLS in our case is that we will need the server certificate to verify the server. Traditionally we will need to either pre-install certificates on the mobile device (makes "bring your own device" more difficult) or register with a certificate authority (depend on third party). In our case the the server certificate is already on the smart card and we can install it on the mobile device. An added benefit of this is that if the mobile device is rogue and tries to connect to the wrong server; the data sent to the server will be encrypted by the smart card.

Further we will need the user to authenticate with the authority. We have two options in order to achieve this. First option is that the user use a username and password combination directly with the authority, but

considering the binding is normally a one time case a more simplified process may be to hand out a one time code along with the smart card. One could also look into distributing one time codes through e-mail or a text message (SMS).

The second option is that the user inputs a pin code to the smart card and if the pin code is correct the smart card can verify that the user is the user he claims to be. This option requires very little overhead and saves a lot of resources in that regard.

We have described how the parties can authenticate each other, but we will need to describe this as a unified process (refer to section 3.1.4) and identify attack vectors and weaknesses (refer to section 3.1.5).

3.1.4 Proposed solution

Pre-conditions

The authority issues the smart cards and administrates the server. During the setup of the smart card the public key and certificate of the server must be installed on the smart card. The public key of the smart card must also be extracted and stored on the server. This creates a base for all future processes.

Verification package

A verification package is a package containing all the information a third party server needs to authenticate the smart card and mobile device. Firstly the mobile device public key, the smart card public key and generated AES key is signed by the smart card. Then we encrypt this package with the public key of the third party server. Figure 3.3 visualizes this structure.

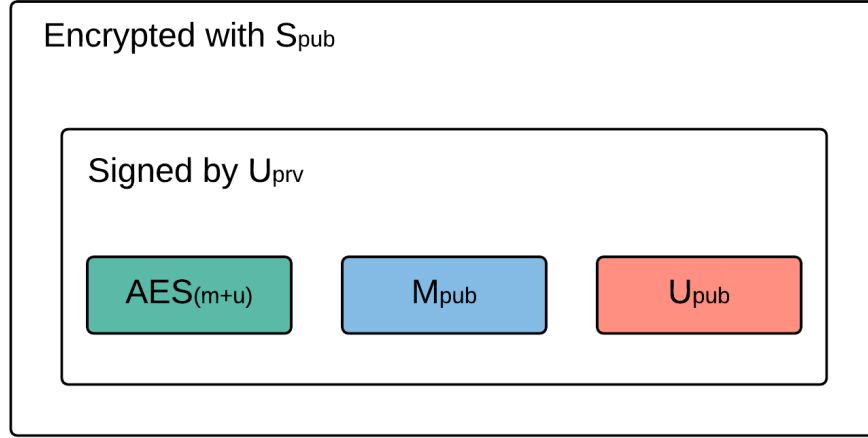


Figure 3.3: Verification package structure.

Abbreviations

U - Users smart card

M - Mobile device

S - Server, representation of authority

H_0 - Verification package

$\{Entity\}_{pub}$ - Public key of an entity (U, M, S)

$\{Entity\}_{priv}$ - Private key of an entity (U, M, S)

$\{AES\}_{Entity+Entity}$ - AES key of two entities (U, M, S)

1. Install Android application on mobile device (M) and insert smart card (U).
2. M generates RSA key-pair and store in TrustZone.
3. M sends M_{pub} to U and requests verification package (H_0) from (U)).
4. U asks for a PIN code.
5. M provides PIN code.
6. U generates H_0 (refer to figure 3.3) and sends it to M.
7. M connects to the server (S) and sends (H_0) to S.
8. S decrypts (H_0) using S_{priv} and verifies the signature of U.

9. S saves $\text{AES}_{(M+U)}$ for safekeeping, signs M_{pub} and sends the signed M_{pub} to M.
10. M forwards the signed M_{pub} to U.
11. U verifies that M_{pub} was signed by S and if successful U sends U_{pub} to M.

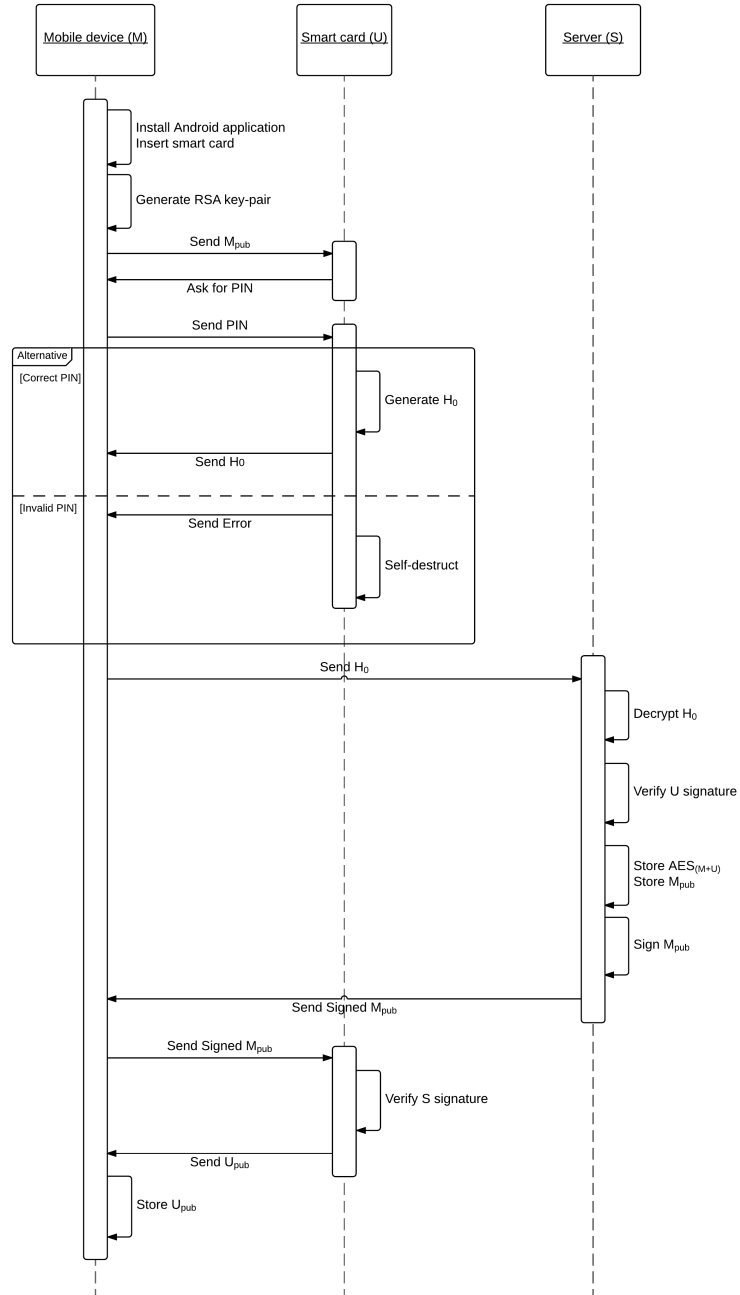


Figure 3.4: Sequence diagram for binding mobile device with smart card.

The end result of the transactions is that the smart card and mobile device have shared their public keys through the trusted third party and can thus communicate securely. The server will also have a record of the transactions and the parties. If we chose to do so we can also save a backup of the first symmetric key on the server.

Potentially we could add more steps to the process to further heighten the security. In step 7 we could add that a user may need to answer a challenge such as provide a one time password (OTP). This would add more overhead and require more resources administrating.

A direct consequence of a successful binding is that the smart card is now locked to the mobile device. Inserting the smart card into a different device will simply not work due to the fact that the smart card has the public key of the original device and they have already agreed upon a symmetric key. To further enhance this trait we can once in a while challenge the mobile device which requires the private key of the original binded device to solve (e.g. challenge is encrypted with M_{pub}).

3.1.5 Potential attack vectors

This solution relies heavily on correct use of protocols such as TLS (communication) and correct key generation. We assume that all cryptographic functions we use are used correctly and all keys are of such lengths that they are cryptographically strong. Now that we have established that requirement we can look at the different attack vectors.

Rogue technical party

The three technical parties involved are the server, the mobile device and the smart card. As discussed previously "the authority" issues the smart cards and administrates the server. Since the public keys and certificates are exchanged before the smart card is distributed the server is able to detect if there are a rogue/fake smart card trying to bind to a mobile device. If the mobile device tries to connect to the wrong server (man-in-the-middle attack, wrong URL, etc.) and the server tries to pose as a legit server, it will not be able to complete the binding process due to needing the matching private key for the public server key on the smart card.

Thus the only attack vector on technical parties is where the mobile device is rogue. By rogue in the context of the mobile device we mean compromised

as in rooted or malware/spyware. In our solution we have no way of knowing if the user is binding a rogue mobile device. The end result is that we have securely binded the mobile device and smart card, but the mobile device cannot be trusted.

To combat this we need to do two things. Firstly we need to educate the user on mobile security and how they should not install applications from untrusted sources etc. Secondly we can run tests on the mobile device to try and detect if the mobile device is rooted or has malware/spyware. This can prove to be hard as it is very difficult, if not impossible, to detect malware/spyware which operate with root access. Google has been working on a security framework, SafetyNet, which goal is to detect if a device has been tampered with or is infected [24]. In order to decide if this is sufficient we would have to do more research on SafetyNet specifically.

Rogue user or administrator

Potentially we can have a rogue user which deliberately installs malware/spyware on their mobile device to compromise our system. We will disregard this case as if we have a rogue user we have bigger problems than a compromised mobile device. It is also important to note that any information the mobile device receives the user is also likely to know regardless and can thus release this information independent from the mobile device.

The bigger problem would be a rogue administrator. The administrator would have access to the initial setup of the smart cards and may extract the private key of the server. Even though this has more impact than a rogue user we are very limited on what we can do to protect against it. We can make it near impossible to extract private keys, logging and require more than one administrator, but it will still be possible to cause harm. Although the same principle applies here: if you have a rogue administrator you have bigger problems than smart card binding.

3.1.6 Additions

In step 9 and 10 of the proposed solution we can add a payload to the signed M_{pub} . One of the uses for this payload may be to send information on how the smart card should handle communication, key generation, encryption & decryption as well as administration. More on this in section 3.2.

3.2 Security policy enforcement

3.2.1 Definition

A security policy defines what measures a system needs to follow in order for the system, organization, group, etc. to be secure. Security policies are not necessarily a technological restriction/rule and can exist as a socially enforced rule. Examples of security policies are:

- All employees needs to have a background check.
- All company doors will be locked after 4 pm.
- Password must be changed once a month.
- Sensitive data must be encrypted with AES-256.

3.2.2 Problem description

Enforcing security policies via a mobile device is not a new concept and there exists multiple third party solutions for enforcing them. One example is Microsoft Exchange ActiveSync which enforces policies such as minimum password length, disable camera and application blocking [6]. ActiveSync utilizes the fact that a user must connect through Microsoft Exchange Server in order to access company resources and verifies if the mobile device has enforced the policies through the established connection [10].

The problem in these types of solutions lies in the fact that you cannot trust the mobile device to actually enforce the policies. How does the server know if the mobile device is telling the truth about policy enforcement? What if the mobile device says it requires the user to enter a password, but does not do it?

3.2.3 Goals

By using smart cards in the context of policy enforcement we wish to achieve the following:

- Policies are enforced.
- Not possible to spoof policy enforcement by the mobile device.

- Policies cannot be tampered with.

Optionally we want to achieve the following:

- Policies can be updated.

3.2.4 Shift responsibility to a trusted party

One way of making sure that policies are enforced is to give the responsibility of the action to a trusted party. Imagine that company A have a policy which requires their employees to update their password on their personal computers once a month. If the user profiles only exists locally on the computers company A has no way of checking if the users update their passwords and run the risk of the users saying they have updated the password without doing so. To combat this the user profiles are moved to company A's server and the personal computers now do a lookup for the user profiles on the server. In this case A now have control over the user profiles and can check if the passwords are updated.

The limiting factor to a solution like this is that the trusted party might not be able to perform the job. A trusted server might not be able to enforce locking doors after 4pm just as a smart card is not able to perform all jobs we want it to do. A big part of the job is to identify which part of a security policy action we can move to the smart card to enforce the security policy.

3.2.5 Proposed solution

Relevant policies for a smart card

The smart card is limited in what kind of policies it is able to enforce. It cannot enforce policies regarding forcing the mobile device into doing things only the mobile device controls. The smart card can provide vital data needed for performing an action, but it is up to the mobile device to actually perform the action. This effectively rules out policies such as, "The mobile device must encrypt all files stored locally.", since we can only provide the keys to do so, but the mobile device has to perform the action. We have to assume that the mobile device, more specifically the running application, wishes to perform the action.

The core abilities of a smart card are:

- Generate keys.
- Store keys.
- Sign data.
- Encrypt & decrypt small amounts of data.
- Store and handle variables.

We can make the application rely on the keys generated and stored in the smart card and as a result we have full control over the keys. The smart card can as a result enforce policies such as key rotation, key size and key availability (unlock key with PIN).

Installing policies

One disadvantage of using smart cards is that once an applet has been installed it is a static application. It is not possible to add new code to a running applet. What we can do is to program all policies we may wish to utilize and disable them. With this technique we can dynamically turn on and off policies, given that we are able to communicate with the card. The first premise is to install all possible security policies we may need on the smart card before shipping the smart card to the user.

Enable and update policies

To enable policies or set parameters for the policies we require a protocol to exchange information with the smart card from a server. One of challenges we are "How do we ensure that the mobile device relays policy updates to the smart card?". One solution is to have the smart card lock itself and require a verification package from a trusted server. To ensure that the server is the only party that can provide the verification package, is to send a challenge from the smart card which only the server knows the answer to (shared key/secret). Refer to figure 3.5 and figure 3.6 for challenge and challenge response.



Figure 3.5: Smart card policy challenge.

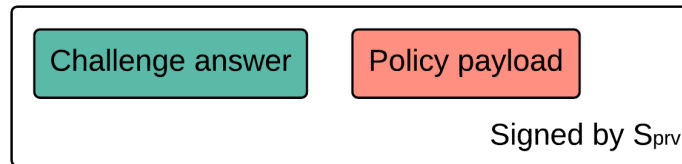


Figure 3.6: Smart card policy challenge response.

Challenge transaction

U - Users smart card
 M - Mobile device
 S - Server, representation of authority
 OH - Original hash
 NH - New hash
 $\{\text{Entity}\}_{\text{prv}}$ - Private key of an entity (U, M, S)

First we assume the binding of card and phone from section 3.1 was successful. Secondly we assume that the server and smart card has a shared secret: a securely generated 256-bit AES key.

1. U generates a challenge which is a long random hash (OH).
2. U signs OH with U_{prv} .
3. U sends the signed OH package to S via the mobile device.
4. S computes new hash (NH) using the AES key S and U agreed upon.

5. S signs NH and the policy update.
6. S sends the signed NH package (with policy update) to U via the mobile device.
7. U computes the new hash and compares it to the NH it received.
8. U applies policy updates.

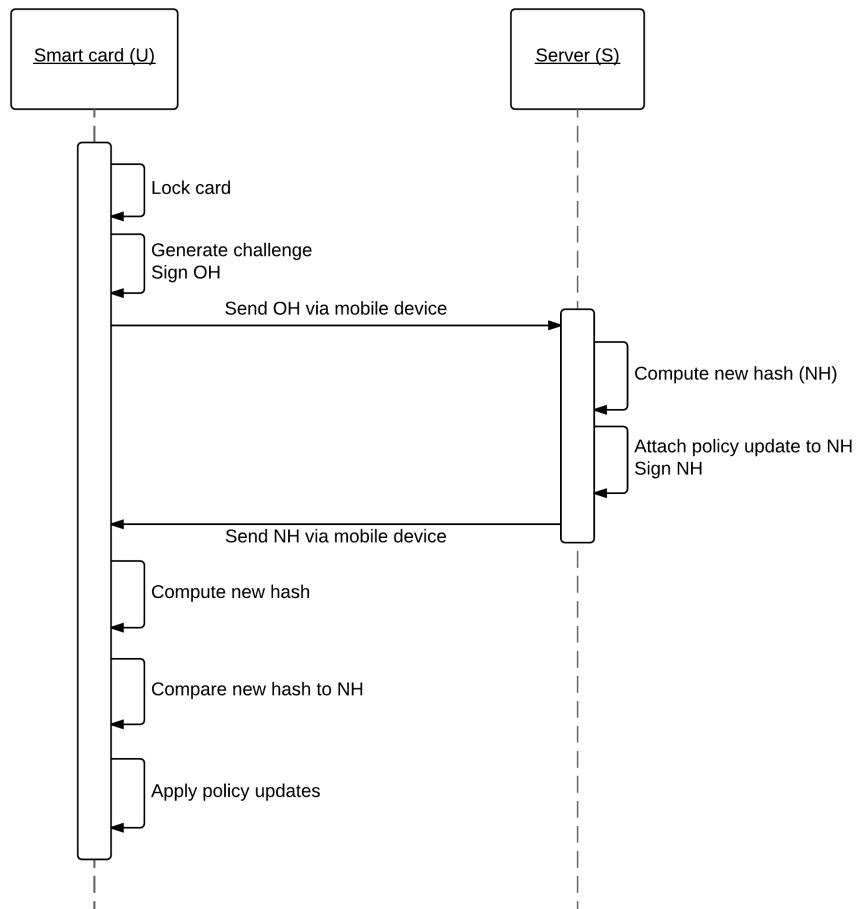


Figure 3.7: Smart card policy challenge.

Policy format

When designing the format of the policy package there are two things to keep in mind. It should be human-readable for easy modification and not deviate too far from a machine-readable format as the smart card will need to interpret it. Another thing to take into consideration is that data being sent to the smart card, must be converted to hex.

We can utilize JSON to make human-readable policies and as an added bonus JSON is readable for most programming languages. Listing 3.1 shows how this can be structured.

Listing 3.1: Human-readable policies in JSON.

```
1 {  
2   "policies": [  
3     {  
4       "id": "19",  
5       "description": "PIN attempts",  
6       "enabled": "true",  
7       "attempts": "3"  
8     },  
9     {  
10      "id": "21",  
11      "description": "Keylength (AES)",  
12      "enabled": "true",  
13      "keyLength": "256"  
14    }  
15  ]  
16 }
```

Recall section 2.2.2 where we described how a Command APDU must be structured. In the header we can use INS as a flag for "policy update instruction", for instance 09. Next we have to look at what we technically want to achieve:

1. Set boolean variable to true, depending on policy ID and "enabled" flag.
2. Set other variable values.

In the body we will use the payload data field to send information on the policy updates. The incoming data will be in byte format. Mapping bytes

to variables could normally be solved using `HashMap` and map entries with `<byte, Object>`; the first parameter is the incoming byte command and second parameter being the variable we want to manipulate. `HashMap` is not a part of the java smart card API and we need to do our own hardcoded manual mapping. The result is a rigid structure for policies.

The individual policies data structure needs to be carefully crafted and specialized, but we should also focus on making it as dynamic as possible. This is best described using an example. To demonstrate how it can be done, we will use listing 3.1 as example data. The resulting APDU is figure 3.8 and it clearly shows that we have to hardcode how many fields a policy will need.

CLA	INS	P1	P2	LC	"Number of policies"
80	09	00	00	08	02

"PolicyLength"	"Policy ID"	"Enabled"	"Attempts"
03	13	01	03

"PolicyLength"	"Policy ID"	"Enabled"	"KeyLength"	"KeyLength"
04	21	01	01	00

LE
01

Figure 3.8: Example policy APDU with two policies

When designing the smart card code for interpreting the policy APDU we need a registry of some sort for keeping track of how much of the payload each policy uses. Listing 3.2 uses figure 3.8 as incoming APDU.

Listing 3.2: Pseudo code for interpreting policy APDU with java smart card.

```

1  public class cardApplication extends Applet implements ExtendedLength{
2      ...
3
4      //Policies
5      final short offset = 5;
6      short counter;
7
8      //Policy 13
9      boolean enabled13;
10     short attempts;
11
12     //Policy 21

```

```

13     boolean enabled21;
14     short keyLength;
15
16     public void process(APDU apdu) {
17         ...
18         byte[] buff = apdu.getBuffer();
19
20         switch(buff[ISO7816.OFFSET_INS]){
21             case 0x09:
22                 counter = 6;
23                 for(short i = 0; i < buff[offset]; i++){
24                     if(buff[counter+1] == 13){
25                         enabled13 = (buff[counter + 2] != 0);
26                         attempts = buff[counter + 3];
27                     }
28                     else if(buff[counter+1] == 21){
29                         enabled21 = (buff[counter + 2] != 0);
30                         keyLength =
31                             (short)((buff[counter+3]<<8)
32                                 | (buff[counter+4]))
33                     }
34                     counter += (1 + buff[counter]);
35
36                 }
37                 break;
38
39             ...
40
41         }
42         Send(apdu);
43     }
44
45     private void send(APDU apdu) {
46         //Package outgoing buffer
47         //Send response APDU
48     }
49 }
50 }

```

3.2.6 Solution evaluation

Section 3.2.5 described how a smart card can enforce policies and how to manage policies. The solution is complex, intricate, requires a lot of overhead and is very rigid. Despite these drawbacks, using a smart card for policy enforcement could be well worth it. If an organisation need a system where they are in full control and that is tamper proof, a smart card solution is viable option.

3.2.7 Potential attack vectors

Known-plaintext attack

The challenge we use is simply two parties creating the same ciphertext from a hash and then comparing them. We then use digital signing to ensure that the challenge-response cannot be intercepted and spoofed. Since we do not encrypt the challenge-response in any way we have to vary of "known-plaintext attacks" [30]. To protect against this type of attack the smart card and server must use keys that are long and algorithms that cannot be brute-forced. The final solution should use atleast 256-bit long AES keys and as an added measure rotate keys.

Chapter 4

Test Cases

4.1 Setup

In order to do research on how smart cards can have an impact on mobile data security and to perform an evaluation on how effective they are we need to have a proper test environment. We define "proper test environment" as an environment as close to reality as possible.

4.1.1 Equipment

Test device

The device we will be using for deploying the applications and performing tests on is considered to be a mid-range device. The device is a Sony Xperia M2 Aqua smartphone running Android 5.1.1 with the following relevant specifications:

- Chipset: Qualcomm MSM8926-2 Snapdragon 400
- CPU: Quad-core 1.2 GHz Cortex-A7
- RAM: 1 GB

More information on the specifications of the phone can be found on GSMarena.com [29].

Java smart card

We will be using two types of smart cards. The first type is a micro SD memory card (IDCore 8030 MicroSD card) as shown in figure 2.3 produced by Gemalto. The reasoning for using this card for testing is that Gemalto delivers ready-to-use cards along with a framework for communicating with them. The cards we will be using have nothing pre-installed on them and we can freely deploy custom applications to the card. In order to use the provided framework we need a key provided by Gemalto which has a validity period of 120 days.

The second type of card we will be using is a plain hybrid smart card (ref. figure 2.1) with no pre-installed software which is also provided by Gemalto along with a standard card reader. In this case we are not reliant on the framework provided by Gemalto as Android has built in support for NFC communication in the standard SDK.

Both types of card are able to run the same application and thus makes it very convenient when comparing their performance the two card types to each other.

4.1.2 Java card application

The cards we have supports java card 2.2.2 and this is the version we will target. A natural question is "Why don't we target java card 3 and above?". Smart cards used for banking or handling other highly confidential data needs to be evaluated under the Common Criteria [31] standards. Potentially we may handle confidential data and as a result we want smart cards with a Evaluation Assurance Level (EAL) 4 or above. Achieving EAL4 or above is an expensive and long process and the relatively few products have this certification. The micro SD card we have access to are certified with EAL5+, but only supports java card 2.2.2 [12].

Development environment

In order to develop applications for the smart cards we will be using Eclipse 3.2 with java development kit version 1.6.45. In order to develop smart card applications more easily we will use the Eclipse-JCDE plugin [9] which provides a virtual runtime environment along with build tools.

We will be using GlobalPlatformPro (GP) [11] to deploy and manage applets on the physical smart cards. GP is a command line tool and is compatible with our hybrid Gemalto card with reader as well as the micro SD card.

To test the smart card application that is deployed on the physical cards (without going through an Android application) we will be using pyApduTool ?? . pyApduTool is a tool for sending APDUs to a smart card through a card reader or memory card reader and lets us observe how the card behave when receiving and transmitting data.

Goal

The goal of the smart card application was to create an autonomous and easy to extend platform for future tests. This resulted in an application split into three parts.

Initialization

As described in section 2.2.3 all javacard applications must implement the method `Install`. `Install` invokes the constructor of the smart card and this is where all variables that need initialization are initialized. For instance if the smart card application needs to generate keys or random numbers this is where it is done as the constructor will be invoked only once. All buffers that needs to be used should also be initialized here to avoid allocating memory everytime the application is used.

Data processing

In the mandatory `Process` method (refer to section 2.2.3) all data processing takes place. First a built in method in the javacard API, `selectingApplet()`, is invoked. This method checks if the incoming APDU is a SELECT APDU and acts accordingly. If the incoming APDU is not a SELECT APDU the incoming APDU is copied to a new buffer for easier data manipulation. Next we use a switch statement switching over the second byte, INS, to determine which instruction we want to perform. After processing the data and performing the work we want to do (sign data, encrypt, etc.) we copy our response to the outgoing buffer.

Finalization

At the end of the `Process` invocation we invoke the `Send` method which

takes the data in the outgoing buffer, package it for sending and send it as a response APDU.

The result

What we end up with is a test platform where we are only concerned with declaring variables, initializing variables and writing code for the specific test case. Listing 4.1 shows pseudocode for the java card application with the extendable areas highlighted.

Listing 4.1: Pseudo code for javacard test application.

```
1  public class cardApplication extends Applet implements ExtendedLength{
2
3      //Variable declarations
4
5      private cardApplication() {
6          //Variable initialization
7      }
8
9      public void process(APDU apdu) {
10         //Process incoming APDU
11         if (selectingApplet()) {
12             return;
13         }
14         buff = apdu.getBuffer();
15
16         switch(buff[ISO7816.OFFSET_INS]){
17             case 0x00:
18             case 0x01:
19                 ...
20             case 0xff:
21             default:
22
23         }
24         Send(apdu);
25     }
26
27     private void send(APDU apdu) {
28         //Package outgoing buffer
29         //Send response APDU
30     }
31 }
```

4.1.3 Android application

IDE

Android Studio [5] is the official IDE for Android application development. Android Studio is based on IntelliJ IDEA [14] and provides many automated tools for building, packaging and publishing Android applications.

3rd party libraries

As mentioned in section 4.1.1 Gemalto provides a java library, IDGo800, for using their smart cards.

”IDGo 800 for Mobiles is a cryptographic middleware that supports the Gemalto IDPrime cards and Secure Elements on Mobile platforms: Contact and contactless smart cards, MicroSD cards, UICC-SIM cards, embedded Secure Elements (eSE) and Trusted Execution Environment (TEE).” (Gemalto.com [13])

The part of IDGo800 SDK we are interested in is very small and enables us to send custom APDUs to micro SD smart cards.

We will be using the ”android.nfc” package in order to communicate with NFC smart cards. This package is included in the standard Android SDK which in turns means that all Android devices with a NFC reader and minimum API level 9 [4] can use our library.

Application

We used the same approach on the Android application as on the smart card application; an autonomous and easy to extend platform for tests. This resulted in a new library, ”smartcardlibrary”, which sole purpose is to transmit APDUs as easily as possible.

Smartcardlibrary has two main functions:

1. Communicate with NFC card
2. Communicate with mSD card

To send APDUs to a smart card, `NfcSmartcardController` or `MSDSmartcardController` (depending on smart card type) must be instantiated and the application must know the application identifier of the smart card application. Further the current activity must implement `NfcSmartcardControllerInterface` or `MSDSmartcardControllerInterface`

(depending on smart card type) in order to be notified when the transaction is complete. Listing 4.2 shows an example implementation on how an activity may utilize the library for NFC smart cards.

Listing 4.2: Java code example showing how to send and receive commands to a NFC smart card.

```
1
2 public class PayloadActivity extends AppCompatActivity implements NFCSmartcardControllerI
3     NFCSmartcardController nfcsc;
4     ...
5
6 private void initNFCCommunication(){
7     if(nfcsc == null) {
8         nfcsc = new NFCSmartcardController(this, this);
9     }
10
11     String AID = "0102030405060708090007";
12     String hexMessage = "95404F3FB1";
13     String cmd = "06";
14     String p1 = "00";
15     String p2 = "00";
16
17     nfcsc.sendPayloadDataToNFCCard(AID, cmd, p1, p2, hexMessage);
18 }
19
20 @Override
21 public void nfcCallback(final String completionStatus){
22     if(!completionStatus.equals("OK")){
23         return;
24     }
25     StorageHandler stHandler = new StorageHandler(getApplicationContext());
26     String response = stHandler.readFromFileAppDir(FilePaths.tempStorageFileName);
27 }
28 }
```

In order for the library to perform an asynchronous transaction the library will temporary save the responses from the cards to a file only accessible by the running application. To retrieve the data the current activity should use the included `StorageHandler` class as used in listing 4.2. The library also provides the class, `Converter`, for converting between Strings, hex and byte arrays.

Figure 4.1 shows how the library is structured and the entry point for

applications is through the packages:

- com.master.henrik.controller
- com.master.henrik.statics
- com.master.henrik.shared

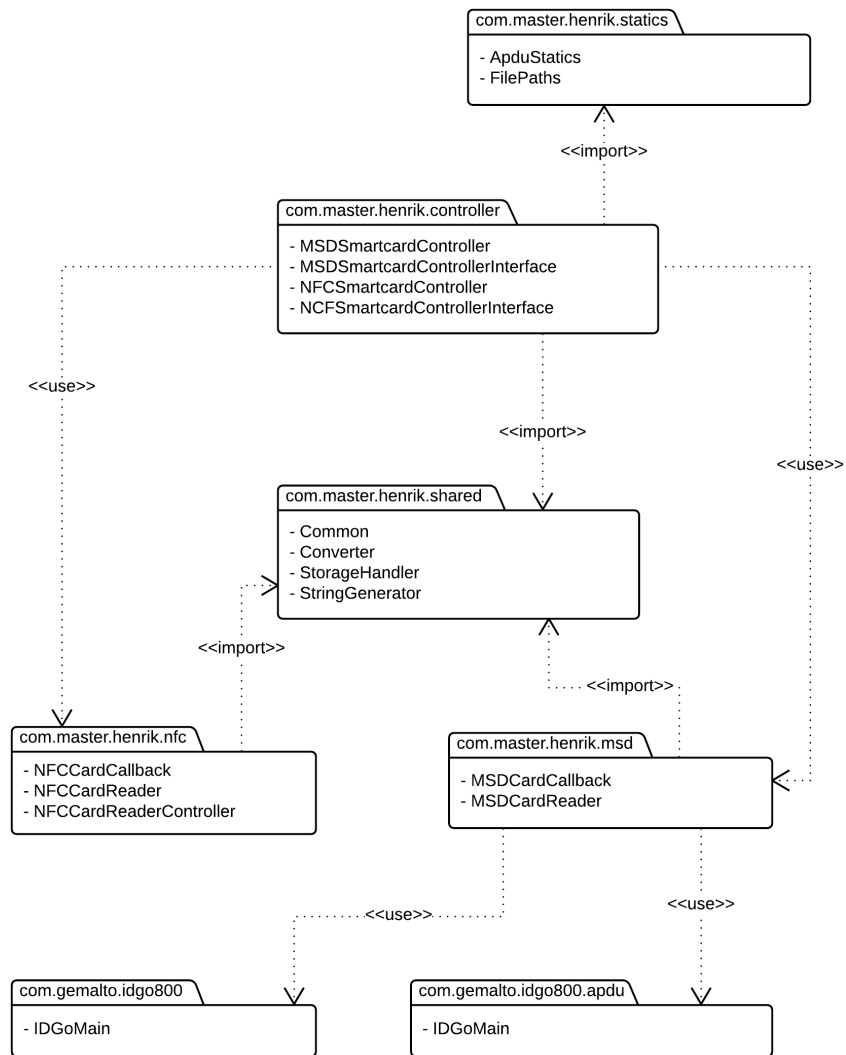


Figure 4.1: Library package diagram.

4.1.4 Limitations

When we started testing the implementation it became evident that the micro SD smart card we had did not support extended APDU. As a result we are not able to perform tests that involve micro SD cards and extended APDU.

4.2 Data Transfer Speed

4.2.1 Description and Motivation

Transfer speed is a very vital for part of the smart card interaction. If the smart card application or the transportation layer are incapable of handling large amounts of the data we will need to take that into account when examining the usability of smart cards. In order to test and eliminate as many variables as possible the smart card is programmed to receive data, initialize a buffer, copy the incoming data to the buffer and send the exact same data in return. Figure 4.2 describes this process using an NFC card as a platform for the Java Card Applet.

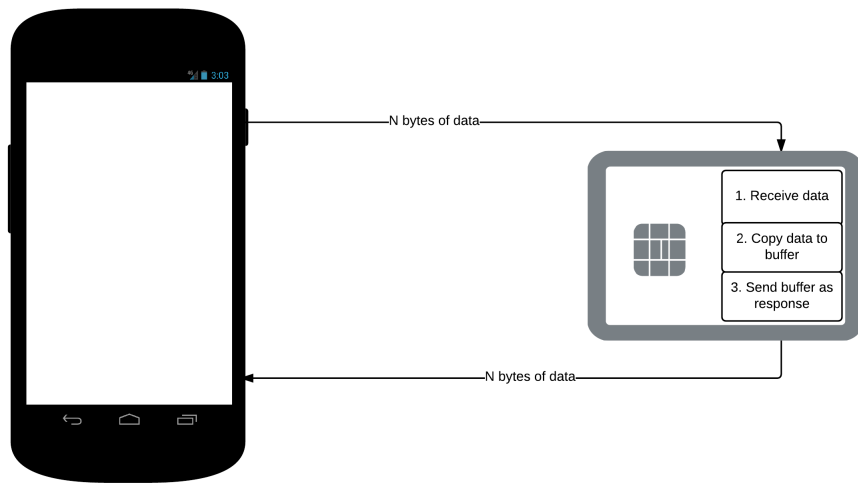


Figure 4.2: Data flow of data transfer speed test for NFC.

4.2.2 Tests and Results

NFC

T1 configuration consists of the Android application sending 255 byte of data to the smart card application, receive the the response and write the response to an internal file. This process is repeated until all of the data is processed.

T2 configuration consist of the Android application sending data to the smart card application using frames of size 255 byte until all data is sent. Simultaneously the responses are written to an internal file using FileOutputStream (provided by the standard Java library).

T3 configuration consist of the Android application sending data to the smart card application using frames of size 32768 byte until all data is sent. Simultaneously the responses are written to an internal file using FileOutputStream (provided by the standard Java library).

Data size (byte)	T1	T2	T3
10000	3,8s	4,1s	3,6s
100000	41,3s	35,0s	24,7s
1000000	602,1s	361,3s	235,1s

Table 4.1: Table of NFC transfer speed test.

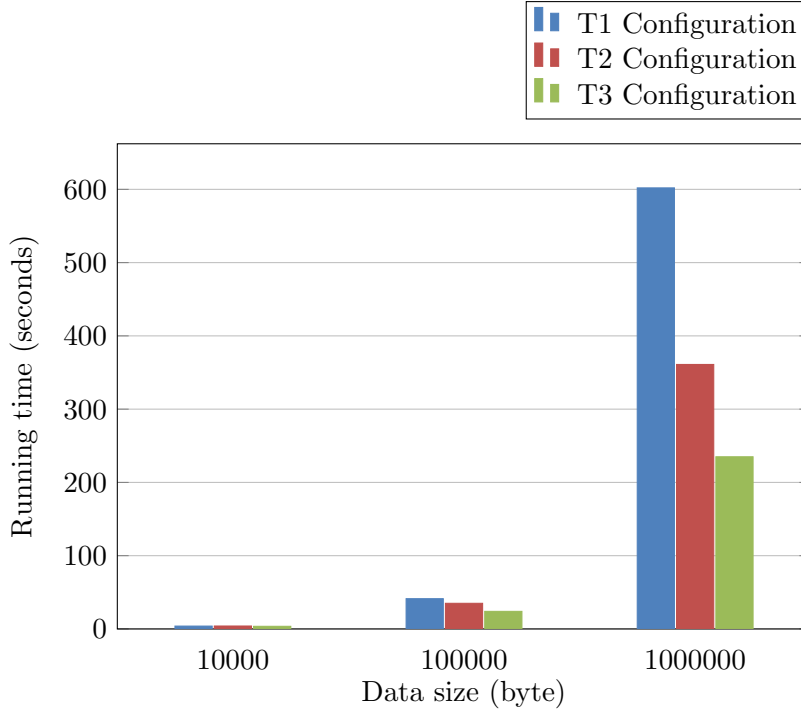


Figure 4.3: Graphical representation of table 4.1.

Micro SD

T1 configuration, from NFC was dropped when testing transfers speed for micro SD as it became clear from previous tests on NFC that T1 is vastly inferior to T2 and T3. A non-asynchronous (not using streams) Android application is not representative of the "real-world" and we decided on not pursuing further test results using this configuration.

T2 configuration consist of the Android application sending data to the smart card application using frames of size 255 byte until all data is sent. Simultaneously the responses are written to an internal file using FileOutputStream (provided by the standard Java library).

We were not able to test T3 configuration as explained in section 4.1.4.

Data size (byte)	T2	T3
10000	3,18s	N/A s
100000	16,14s	N/A s
1000000	142s	N/A s

Table 4.2: Table of micro SD transfer speed test.

4.2.3 Conclusion

From table 4.1 and figure 4.4 we can learn that we are able to optimize the data transfer and processing speed between the Android application and the NFC card. It is also clear that when we are transmitting low amounts there are virtually no difference between the configurations; T1, T2 and T3. The differences are more prominent when the data amounts increases. Even though we achieved an improvement of approximately 60 % from T1 to T3 when sending 1 MB of data, the process is still time consuming.

If we compare the test results for T2 configuration on the NFC card and micro SD card we can clearly see an improvement on the micro SD card. The micro SD card had a 60 % better running time over the NFC card when sending 1 MB of data. Although we were not able to test configuration T3 on the micro SD card, results point in the direction of micro SD cards having better performance than NFC cards.

Even though we are able to optimize and improve data transfer speeds, we are still very far from transferring and processing large amounts of data quickly. We have to take this into account when evaluating areas of use for the smart card. Transfer and processing speed rules out many areas concerning large amounts of data, such as full data encryption.

4.3 Symmetric-key Cryptography

4.3.1 Description and Motivation

We want to discover the encryption abilities on the smart card and decide if it is feasible to let the smart card handle the encryption of confidential data. From the smart card documentation we know that we are able to use AES to encrypt data, but we do not know how long it will take to encrypt the

data. We will need to perform a running time tests with different amounts of data in order to determine the performance of the smart card.

4.3.2 Test setup

The framework we are using is designed around extended APDU and the test platform we have designed in javacard utilizes extended APDU. As a result we are not able to use the micro SD cards (as described in section 4.1.4) and we will be using the NFC smart cards.

The encryption algorithm we will use is AES cipher algorithm with block chaining (CBC). The version of javacard that we are using along with our smart cards limits us to using 128 bits keys and no padding. More specifically the only working AES algorithm from javacard is `ALG_AES_BLOCK_128_CBC_NOPAD`, even though the javacard documentation for `Cipher` supports more algorithms [19]. Others have encountered the same discrepancy [26] suggesting that only three of the twelve supported algorithms works, but there exists no official information on the issue.

`ALG_AES_BLOCK_128_CBC_NOPAD` is as the name suggest an algorithm with no padding. The block size the AES algorithm expects is 16 byte and as a result we will need to pad the data ourselves on the mobile device.

4.3.3 Results

Data size (byte)	Elapsed time
16	0,15s
10000	20,18s
32000	61,81s
100000	183,78s
1000000	1835,49s

Table 4.3: Table of AES encryption speed test.

4.3.4 Conclusion

From the test results we can learn that encrypting data on the NFC smart card takes a lot of time. Encrypting 1MB of data uses approximately 30

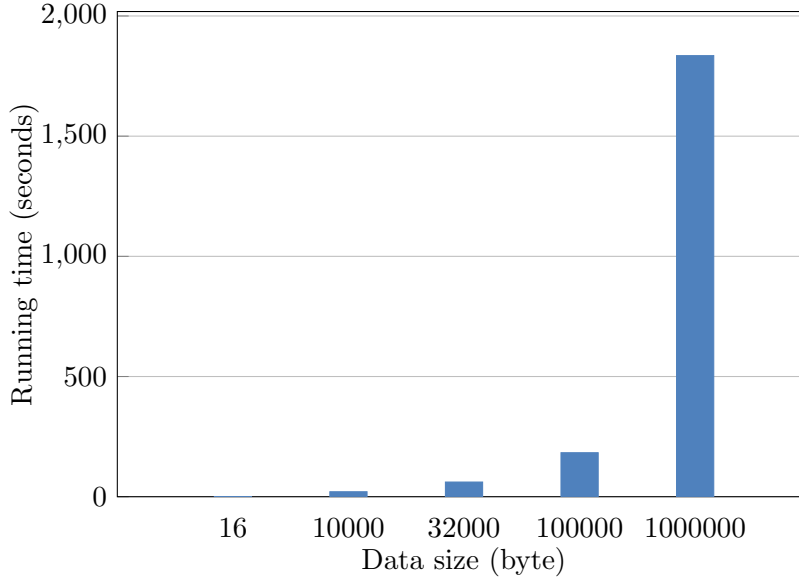


Figure 4.4: Graphical representation of table 4.3.

minutes, which from a real world perspective is an unacceptable amount of time. Using the NFC smart card for full encryption of user data is in other words not achievable and we will need to look for other options for encryption.

Encrypting 16 bytes of data uses 0,15 seconds. A use for the encryption capabilities on the smart card may be to encrypt small amounts of data such as GPS coordinates. GPS coordinates can be represented by only 16 bytes (depending on accuracy). One could also imagine that we will only need to encrypt parts of a document, and as long as we keep the data size small we can let the smart card do the encryption.

4.4 Binding card and mobile device

4.4.1 Motivation

In section 3.1 we describe and motivate a solution where the we want to bind a mobile device to a smart card. We find it important to do an empirical test of the solution due to the fact that we have time constraints regarding

running time. The parts of the binding process we want to test is:

- Mobile device is able to transfer public key to smart card.
- Smart card can store the public key from the mobile device.
- Smart card can generate the *verifaction package* from section 3.1.4.

4.4.2 Implementation

In light of the parts of the binding process we want to test the outline of the implementation will be:

1. Mobile devices asks smart card if its authenticated with PIN.
2. Smart card responds with yes/no and amount of PIN tries remaining.
3. Mobile device prompts user for PIN and sends it to the smart card.
4. Smart card verifies PIN or the process skips back to step 2.
5. Mobile device sends it public key to the smart card.
6. Smart card generates the verification package (figure 3.3).
7. Smart card sends the verification package to the mobile device.

Due to the nature of smart cards we will need to hard code this protocol into the android application and the smart card application. We will use the P1 byte in the APDU to define which step of the process we are in, respectively:

- 0x01 for step 1 and 2.
- 0x02 for step 3 and 4.
- 0x03 for step 5,6 and 7.

To manage PIN verification and management we will use `OwnerPIN` class from the javacard framework [8]. After the PIN is set on the card during installation we can utilize the methods: `isValidated()` for checking if the right PIN is already provided, `check(byte[] pin, short offset, byte length)` for checking if the provided PIN is correct and `getTriesRemaining()` for getting remaining tries.

All public keys are represented as byte arrays when they are transmitted between the mobile device and the smart card. The format for the byte

array is `|ModulusLength|Modulus|ExponentLength|Exponent|` to allow for extension of key length and dynamic importing. After the APDU is received the public key is stored in a `RSAPublicKey` object for storage.

When we construct the verification package on the smart card we have to convert the public key of the smart card over to the same format as the mobile device's public key. After we have transformed all relevant keys (see figure 3.3) to byte arrays we can finally put them together, sign the package and encrypt it with the public key of the server.

4.4.3 Limitations and challenges

Out of memory

We are dealing with many different byte arrays in our solution, and due to the design of smart cards we will need to allocate memory for these byte arrays when the smart card is initialized. The size of these byte arrays are dependent on the key sizes we use. Allocating 5 byte arrays of length 500 (which is plenty for 2048-bit keys) is independently fine, but if the smart card application allocates a lot of resource alongside this solution we need to be careful not running out of memory.

Lots of code <http://askra.de/software/jcdocs/app-notes-2.2.2/garbagecoll.html>

Initialization of public keys

We store the public key of the mobile device on the smart card using `RSAPublicKey` class and invoke the methods `setModulus(byte[] buffer, short offset, short length)` and `setExponent(byte[] buffer, short offset, short length)` to set the incoming modulus and exponent. The problem with this solution is that you are not able to use the two setters without having an initialized `RSAPublicKey` and the way you initialize a `RSAPublicKey` is by generating the key during installation. This is highly timeconsuming and we essentially overwrite the generated key with the mobile device key. This process is very unnecessary seen from a resource efficient view.

We are not able to find any other way of initializing a `RSAPublicKey` and we find it clear that transferring a public key to the smart card is not an intended feature. We are able to make it possible, but this comes at a cost of running time.

Limitation on RSA key length crypto
Public keys act weird - init on card first
hardcoded

4.4.4 Conclusion

Chapter 5

Conclusion

5.1 Conclusion

5.2 Future work

DONE - NOTHING TO DO HERE

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