Using the Estonian Electronic Identity Card for Authentication to a Machine (Extended Version)

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Abstract. The electronic chip of the Estonian ID card is widely used in Estonia to identify the cardholder to a machine. For example, the electronic ID card can be used to obtain benefits in customer loyalty programs, authenticate to public printers and self-checkout machines in libraries, and even unlock doors and gain access to restricted areas.
This paper studies the security aspects of using the Estonian ID card for this purpose. The paper shows that the current use of the ID card provides little or no assurance to the terminal about the identity of the cardholder. To demonstrate this, an ID card emulator is built, which, to the extent possible, emulates the electronic chip of the Estonian ID card and is able to successfully impersonate the real ID card to the terminals deployed in practice. The exact mechanisms used by the terminals to authenticate the ID card are studied and possible security improvements for the Estonian ID card are discussed.

1 Introduction

The Estonian state issues several types of identity documents in credit card-size form factor that contain a contact-type smart card chip. These are: identity card, residence permit card, digital identity card and e-resident's digital identity card [28]. In this paper we use the common term "ID card" to refer to these chip cards.

The main purpose of the electronic chip embedded in the ID card is to perform cryptographic operations with two RSA 2048-bit keys stored on the chip. One key is used for authentication and the other for digital signature. The authentication key can be used to sign TLS client certificate authentication challenges and to decrypt encrypted documents sent to the cardholder, while the digital signature key can be used by the cardholder to create eIDAS-compatible [33] qualified electronic signature (QES). The use of cryptographic operations requires the cardholder to authenticate using a PIN code.

A popular use case in Estonia is to use the ID card as a credential to electronically identify oneself to a machine. Several large merchants in Estonia allow the ID card to be used as a customer loyalty card [7], providing access to loyal customer benefits once the ID card is inserted in the merchant's terminal. Similarly, the ID card can be used to authenticate to self-service printing machines and self-checkout machines in libraries. Pharmacies use the ID card chip to look up the drugs prescribed using the digital prescription system. There are also some public and less public security installations where the ID card can be used as an entrance card to unlock the door and gain access to restricted areas [6]. The use of the ID card is convenient, as every resident of Estonia is supposed to have one, and the use of such universal identification token avoids the need to carry around a large number of service provider-specific identification tokens.

However, one common characteristic observed in this type of identification is that ID card is being authenticated without requiring the cardholder to enter the PIN code. This means that the cryptographic capabilities provided by the card are not used to authenticate the chip. The card terminal simply reads some cardholder identifier stored on the card and uses it to decide if the access to the service should be granted.

In this paper we study how the smart card terminals deployed in practice authenticate the ID card chip. We do this by building an ID card emulator, which, to the extent possible, emulates the chip of the real ID card and logs the commands received from the terminal. We discuss the security aspects of using this type of chip authentication and also analyze the risks to the cardholder of inserting the ID card in an untrusted terminal. We acknowledge that for certain ID card use cases discussed in this paper the risk of fraud is so low that secure authentication solution may not be needed. The analysis of fraud feasibility, however, is not in the scope of this study.

The paper is structured as follows. Section 2 of this paper describes the current ID card chip authentication mechanism and the problems with it. Section 3 analyzes the security risks to the cardholder of inserting the card in a malicious terminal. Section 4 describes the design of the ID card emulator. Section 5 describes the results of using the ID card emulator in the terminals deployed in practice. Section 6 discusses possible improvements to the current card authentication mechanism. Finally, Section 7 concludes the paper.

2 Card Authentication

To identify the cardholder, the terminals deployed in practice read the publicly readable personal data file that resides on the chip of the Estonian ID card. The records contained in the personal data file are shown in Table 1.[4] To read the records, the terminal has to send several Application Protocol Data Unit (APDU) commands to the smart card and read the responses. The example for reading the 5th record (nationality code) from the personal data file is shown in Table 2. In practice, the process of reading the whole personal data file takes around half a second.

Table 1. Contents of a personal data file stored on an ID card [34, Sect. 10]

No.	Content	Example	Length (bytes)
1	Surname	AIKOVSKI	max 28
2	First name line 1	IGOR	max 15
3	First name line 2		max 15
4	Sex	M	1
5	Nationality code	POL	3
6	Date of birth	01.01.1971	10
7	Personal ID code	37101010021	11
8	Document number	X0010536	8 or 9
9	Expiry date	13.08.2019	10
10	Place of birth	POOLA / POL	max 35
11	Date of issuance	13.08.2014	10
12	Permit type		max 50
13	Notes line 1	EL KODANIK / EU CITIZEN	max 50
14	Notes line 2	ALALINE ELAMISIGUS	max 50
15	Notes line 3	PERMANENT RIGHT OF RESIDENCE	max 50
16	Notes line 4	LUBATUD TTADA	max 50

[4] The digital identity cards issued before December 2014 have only the document number (field no. 8) filled. These cards will expire by December 2017.

Table 2. APDU commands for reading the 5th record from the personal data file

Command	Command APDU	Response APDU	Description
`SELECT FILE`	00 A4 01 0C 02 EE EE	90 00	Select EstEID DF
`SELECT FILE`	00 A4 02 0C 02 50 44	90 00	Select personal data file
`READ RECORD`	00 B2 05 04 00	61 03	Read 5th record
`GET RESPONSE`	00 C0 00 00 03	50 4F 4C 90 00	Retrieve 3 byte response

For the purpose of cardholder identification the personal ID code (record no. 7) suits the best. The personal ID code stays the same for the lifetime of the cardholder and is the standard identifier used by Estonian information systems to uniquely identify a person. The personal ID code, however, is not just a unique identifier – it encodes the person's date of birth, sex and the district where the code has been issued.

2.1 Document Expiration and Revocation Checking

To verify that the card has not expired and is not revoked, the terminal can check the expiry date (record no. 9) and use the document number (record no. 8) to run an online check against the public online document validity service provided by Estonian Police and Border Guard Board [8]. Alternatively, the terminal can check the validity of X.509 certificates stored on the card using OCSP service provided by the CA free of charge. However, since the certificates in the card can be revoked without revoking the identity document, the validity status of certificates may not reflect the validity status of the document. For example, the cardholder could have revoked the certificates only to disable the usage of cryptographic functionality of the card. On the other hand, it is a popular practice in case of a lost or stolen card to temporarily suspend the validity of certificates in hope to later find the card and terminate the suspension. The identity document validity life-cycle, however, does not allow to temporarily suspend the validity of the document.

2.2 Card Impersonation

The data records stored in the personal data file are not cryptographically protected, therefore the terminal has to trust that the data received has not been modified and is read from an authentic ID card. With cheap programmable smart cards available in the market this trust assumption does not hold in practice. In Sect. 4 we demonstrate the design of a fake ID card chip that is able to trick the terminals into accepting the fake chip as a genuine ID card, and respond to the terminal with arbitrary data contained in the personal data file. This makes the schemes relying on chip authentication vulnerable to cardholder impersonation attacks.

2.3 Barcodes and Machine Readable Zone

An alternative method for automated ID card identification is to scan the barcode or the machine readable zone available on some types of ID cards.

The identity cards and residence permit cards issued since 2011 contain two barcodes (see Fig. 1) on the back of the card. The first (topmost) encodes the personal ID code of the cardholder, but the second encodes the document number. The data in the barcodes is encoded using the "Code 128" barcode format. The digital identity cards and e-resident's digital identity cards contain only the barcode encoding of the document number on the back of the card.

All ID cards, except digital identity cards and e-resident's digital identity cards contain a machine readable zone (MRZ) in travel document "Type 1" format on the back of the card (see

Fig. 1). The data in the MRZ encodes issuing country code, document number, date of birth, sex, expiry date, nationality code and the name of the cardholder. Since the data encoded in the MRZ follows the ICAO standard for machine readable travel documents, the data does not include the country-specific Estonian personal ID code, not even in the optional fields of the MRZ. Hence, the MRZ on ID cards does not suite well for the purpose of cardholder identification.

There are merchants who scan the barcode to identify the cardholder (e.g., Euroapteek and Euronics). This type of card authentication may provide better protection against card impersonation assuming that the operator processing the card performs a thorough card inspection and is able to spot a forged barcode. The focus of this paper, however, is solely on the card authentication methods that interact with the chip of the ID card.

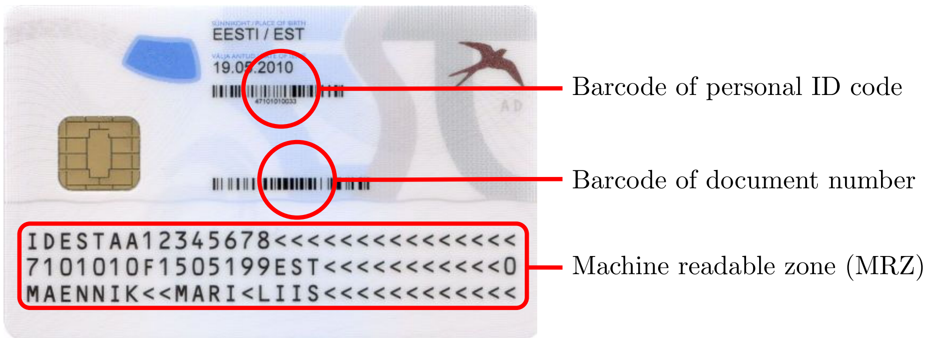

Fig. 1. Back of the identity card (cards issued since 2011) [10]

3 Attacks by Malicious Terminal

The lack of cryptographic assurance in the chip authentication process allows a malicious cardholder to deceive the terminal. There are, however, also the security risks for the cardholder if the ID card is inserted in a malicious terminal. In this section we discuss these risks.

3.1 Cardholder's Privacy Compromise

While the personal ID code is the only record needed to identify the cardholder, a malicious terminal can read other records from the personal data file, such as place of birth or the information about the residence permit. The reading of expiry date and document number, however, may have a legitimate need if the document expiration and revocation checks are to be performed (see Sect. 2.1). Without the data stored in the personal data file, there is also other publicly readable information available on the chip, such as X.509 public key certificates, private key usage counters and PIN code retry counters.

The X.509 certificates stored on the ID card [34, Sect. 13] contain no personal information other than the personal ID code and the name of the cardholder. The certificates can also be obtained from the public LDAP directory maintained by the CA. Instead of reading the personal data file, the ID code to authenticate the cardholder could be extracted from the certificate. This approach, however, is not used in practice, since it is faster and more simple to read a single record from the personal data file. On the other hand, by verifying the signature on the certificate, the terminal could at least obtain a cryptographic assurance that a person with such a name and personal ID code exists.

Private key usage counters [34, Sect. 12.4] show how many times the private key operations with a particular private key have been performed. This information can be used by the terminal to find how active the cardholder is in using the ID card for authentication and digital signing.

The PIN and PUK code retry counters [34, Sect. 12.2] show the remaining PIN code tries, which lets the terminal to find how many times the particular PIN or PUK code has been entered incorrectly. Note, that the retry counter is reset to 3 after each succesful PIN/PUK verification, hence these counters are unlikely to have any other value than 3.

Privacy Risk for the Holders of Residence Permit Card. The residence permit cards are ID cards which are issued to Estonian residents who are not citizens of the European Union [9]. These cards contain an additional contactless smart card chip that runs the ICAO compliant ePassport application storing digitally signed cardholder data, including biometric data. However, to read that information wirelessly, the terminal has to authenticate to the ePassport chip using the Basic Access Control (BAC) mechanism. To create the BAC key the reader has to optically read the machine readable zone (MRZ) and extract the document number, expiration date and date of birth. However, since these fields comprising the BAC key are also stored on the contact chip in the personal data file, a malicious terminal, if equipped with additional contactless reader, can read the data stored on the ePassport chip without the need to scan the MRZ. The additional personal information obtainable this way is the facial image and two fingerprints[5] of the cardholder.

We note that the reading of the facial image may be useful for the purpose of cardholder verification (see Sect. 6.2), although the wireless reading of 20 KB 480x640 pixel facial image from the residence permit card takes around 15 seconds.

3.2 Denial-of-Service Attacks

A malicious terminal can execute denial-of-service attacks against the card, leaving the card in an impaired state. The most straightforward attack is to decrease the PIN/PUK retry counters to 0. This will block the cardholder's access to cryptographic operations forcing the cardholder to visit the ID card customer service point to obtain a new PIN envelope. For cardholders of e-resident's digital identity card such a service does not exist, leaving these cardholders with the only option being to apply for a new ID card. In a similar way a malicious terminal can block the GlobalPlatform [12] applet management key, which will prevent the cardholder from renewing the applet in ID card customer service points or over the Internet.

One could argue that these logical denial-of-service attacks against the ID card should not be of concern, since a malicious terminal can always cause damage, for example, by supplying excessive voltage to the electronic chip. In practice, however, the attacker may have gained only a logical control over the terminal, leaving the application level attacks against the smart card the only option available.

3.3 Unauthorized Use of Private Keys

A malicious terminal could also try to perform private key operations by guessing the 4-digit PIN1 code protecting the authentication key or 5-digit PIN2 code protecting the digital signature key. The probability to guess a random 4-digit and 5-digit PIN code in 3 tries is 0.03% and 0.003%, respectively. In practice, however, the success probability for guessing the PIN can be several times higher, since some of the cardholders may have updated the random PIN generated by the card issuer with a PIN code of their choice. Bonneau and others in [2, Table 3] show that, compared to randomly generated PINs, for human chosen PINs the success probability of guessing 4-digit PIN increases from 0.03% to 5.52% if 3 guesses are allowed.

[5] Fingerprints on the cards issued after 3rd of November, 2014 are additionally protected using the Extended Access Control (EAC) mechanism, which requires terminal authentication.

While this type of attack has a quite low success probability for a targeted attack, an opportunistic attacker being in contact with thousands of cards can succeed in guessing the PIN code for some of the cards. Instead of performing 3 guesses per PIN (which will cause the PIN to be blocked), the attacker can perform only one try per PIN. The cardholder is unlikely to notice that after inserting the card in some terminal the PIN retry counter has decreased. In fact, the malicious terminal can continue the attack once the cardholder returns with the PIN code retry counter reset.

The probability of guessing both PINs for the same cardholder nevertheless is negligible. Therefore, the high risk transactions should always involve both – the authentication and digital signing operations.

4 Design of ID Card Emulator

In this section we show the design of the ID card emulator that we used in the experiments performed in Sect. 5. The purpose of the ID card emulator is to emulate the chip of the real ID card as close as possible. Since the private keys from the real chip cannot be extracted, the operations performed with the private keys cannot be emulated. However, as discussed before, for the purpose of card authentication, the emulation of private key operations is not needed. As we will find from the experiments, in practice only the personal data file feature is used by the terminals.

To implement ID card functionality in a smart card, a programmable smart card supporting Java Card technology was chosen. The Java Card technology allows smart card applications to be written using a subset of Java programming language. Today most of the smart cards in the market run applications written using Java Card technology. The Estonian ID cards issued starting 2011 also use the Java Card technology to implement the required functionality. The source code of EstEID Java Card applet, which is installed on the ID cards in the card personalization stage, is the intellectual property of the card personalizer Trüb Baltic AS and is not public [4]. However, a detailed specification for terminal and chip communication is provided in [34] and [35]. Furthermore, there is an open source implementation of EstEID applet called FakeEstEID [22], which we took as a basis for our ID card emulator. The FakeEstEID applet was modified to implement APDU command logging functionality, add support for arbitrary applet application identifier (AID), implement `GET RESPONSE` emulation for T=0 Case 2 APDUs, and to emulate EstEID v3.5 personal data file format.

4.1 Card ATR Adjustment

Whenever the power or the reset signal is supplied to a card, the card responds with a sequence of bytes called Answer To Reset (ATR). These bytes identify communication parameters supported by the card and optionally may contain historical bytes that typically hold some kind of card identifier. Several generations of Estonian ID cards in circulation respond with different ATRs. Each generation of ID card responds with two different ATRs – cold and warm ATR depending on if the power or the reset signal has been supplied to the card.

Since the ATR returned by the card can be used by the terminal to verify if the inserted card is the Estonian ID card, the ID card emulator had to be adjusted to respond with the ATR of the real ID card. The historical bytes of ATR can be changed within the applet using Java Card API call `GPSystem.setATRHistBytes()`. However, the ATR prefix, which encodes electrical communication parameters of the card, cannot be changed. The solution was to find a blank Java Card whose ATR prefix would match the prefix of the Estonian ID card.

Fortunately, a blank Java Card "G&D SmartCafe Expert 6.0 80K Dual" [11] sold under 15 pounds in small quantities by UK-based seller [32] was found to have the ATR[6] whose ATR prefix `3B F? 18 00 00 80 31 FE 45` matches the ATR prefix of Estonian identity cards issued since 2011. Since this blank Java Card returns a single ATR value for both the cold and warm ATR, we chose to configure the ID card emulator to respond with the cold ATR[7] of the Estonian identity card version issued from October 2014. The inability to emulate both ATRs at the same time is a deficiency of our ID card emulator. The terminals deployed in practice, however, are unlikely to validate both ATRs.

4.2 APDU Logging Functionality

The purpose of the APDU logging functionality is to study how the terminals deployed in practice interact with the ID cards. The logging functionality of the emulator applet writes the received APDU commands to the card's EEPROM storage and later releases them when a specific command is received.

Since in the Java Card each APDU received from the terminal is passed to the selected applet's `process()` method, this method is the central place where all APDU commands received are logged. The smart card technology allows several applications to reside on one card, however, only one applet on the card can be set as the implicitly selected (default) applet. To communicate with another applet, an explicit `SELECT FILE` APDU has to be sent specifying the application identifier (AID) for the applet that should be selected. For the ID card emulator, the emulator applet is set as the default applet. This means that all the commands, including applet selection commands containing non-existent AIDs, will be received and logged by the emulator applet. Additionally to the logging of the received APDUs, emulator applet logs invocations of applet's `select()` and `deselect()` methods.

The applet's `select()` method is invoked automatically when the first APDU is received from the terminal and before it is passed to the applet's `process()` method. The logging of `select()` invocation allows to detect if the card has been reset in the middle of APDU trace. Note that if the terminal powers up the card just to read the ATR, this fact will not be logged, because the `select()` method is invoked only when the first APDU is to be processed. Since the smart card does not have a built-in clock, the timing of the APDUs received cannot be logged either.

The Estonian ID card being emulated supports both electrical transport protocols T=0 and T=1 defined by ISO 7816. To find which communication protocol is prefered by the terminal, applet's `select()` method logs the protocol used in the communication. The protocol used is obtained using `APDU.getProtocol()` Java Card API call.

The invocation of applet's `deselect()` method is also logged. This method is invoked whenever the terminal selects the emulator applet or some other applet residing on the card. The possibility that the applet's deselection is caused by the terminal's explicit selection of the emulator applet itself can be ruled out, because the AID of the emulator applet is set to a random value. The only other selectable applet on the card is the Issuer Security Domain (ISD) with the standard AID `A000000003000000`, which is used for GlobalPlatform's [12] applet management purposes. A legitimate terminal should not communicate with the ISD. However, if it will, this fact will be logged and detected.

From the 80 KB of the card's total EEPROM size, a 4 KB memory buffer was allocated to store logged APDU commands. The amount allocated is more than enough to store the APDU trace of a usual terminal–card interaction.

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[6] `3B FE 18 00 00 80 31 FE 45 53 43 45 36 30 2D 43 44 30 38 31 2D 6E 46 A9` (ATR of SmartCafe Expert 6.0).

[7] `3B FA 18 00 00 80 31 FE 45 FE 65 49 44 20 2F 20 50 4B 49 03` (cold ATR of EstEID v3.5 (10.2014)).

4.3 Visual Imitation of ID Card

Since we wanted to avoid drawing the attention to our fake ID card when using the card in supervised terminals, the white blank of the fake ID card had to be disguised to imitate the design of the real ID card. To avoid possible legal risks of imitating a physical identification document, we decided to imitate the visual design of the digital identity card. The digital identity card does not serve the purpose of physical identification and hence has no facial image nor any security features on it.

We used a scanner to scan the original digital identity card and printed the scan on a sticker paper which was then glued on the fake ID card from both sides. While visually the results were not bad, the added layer created card insertion problems in some terminals and the paper got wet and dirty very fast. A much better result was obtained using "Zebra ZXP Series 3" card printer to print the scanned image on both sides of the white plastic.

Chip Transplantation. A perfect visual imitation of the real ID card could be obtained if the chip from the fake ID card could be transplanted to the plastic of the real ID card. This way even a thorough inspection of the card's security features along with the verification of cardholders facial image would provide no signs about the nonauthentic nature of card's electronic communication. The only way to detect the nonauthentic behavior of the card would be to compare the data read from the chip with the data printed on the surface of the card.

Since we did not wanted to experiment with a real identity card, we tested the feasibility of chip transplantation using the ID card test cards obtained from SK ID Solutions AS [31]. The test card fully replicates the visual appearance of the identity card, including all the security features on it. The only difference from the real identity card is that the test card has the word "SPECIMEN" placed diagonally on the front of the card and the identity information on the card is of a fictitious cardholder. We removed the fake ID card chip from the white blank by heating the back of the card with a lighter for a few seconds. To remove the chip from the test card, we used a utility knife to carefully cut out the chip without damaging the plastic around the chip. The fake ID card chip was then glued to the test card. We found the chip transplantation process (Fig. 2) to be straightforward and reliable, the end result (Fig. 3) leaving no visible trace of the chip replacement (other than the different contact pad layout of the fake chip).

Fig. 2. Cards with the chips removed

Fig. 3. Original vs. transplanted card

5 Card Authentication in Practice

To study the exact mechanisms used by the terminals to authenticate the card, we used the ID card emulator in the most popular public deployments where the ID card is used for authentication to a machine. The protocol trace logged by the ID card emulator was later retrieved from the card and analyzed. Each terminal was tested using four slightly different fake ID cards.

1. The first card was a perfect ID card emulator described in Sect. 4. The card was used to test if the fake ID card was accepted by the terminal and to obtain APDU commands received from the terminal.
2. The second card was the same as the first card, but with the ATR historical bytes set to random values. This card was used to test if the terminal validates the ATR against the list of ATRs of the ID cards in circulation.
3. The third card was the same as the first card, but with a document expiry date in the past and an invalid document number. This card was used to test if the terminal performs document validity checks described in Sect. 2.1.
4. The fourth card was used to test if the terminal supports both ISO 7816 electrical transport protocols. If the terminal preferred T=0 protocol to communicate with the first card, the fourth card was the card with arbitrary ATR supporting only the T=1 protocol, and vice versa. It is not of particular importance which protocol the terminal supports, since all ID cards in the circulation support both protocols.[8]

The results of the tests are summarized in Table 3. The terminals covered in this study were tested from May to July 2017. A more detailed description about the terminals analyzed is documented in the subsections below. The raw APDU traces obtained from the terminals are provided in the Appendix.

As expected, our ID card emulator was accepted by all the terminals tested. This shows that the terminals are vulnerable to card impersonation attacks. The results show that all the terminals perform cardholder identification based on the data from the personal data file and not from the certificates. Most of the terminals read more records from the personal data file than required for cardholder identification. While we do not know if the personal data read is retained by the systems, this practice of excessive personal data reading is troubling.

As we can see in Table 3, most of the terminals check the ATR of the ID card. While it makes the creation of ID card forgery more challenging (see Sect. 4.1), in the past ATR hardcoding has caused newer generation ID cards to be temporarily rejected [25]. Our tests with the third card show that none of the terminals tested perform ID card expiration and revocation checks described in Sect. 2.1. Almost all the terminals support both smart card communication protocols, however, T=0 is widely preferred.

ID Card's Use in Payment Terminals. The ID card's use as a loyalty card is a popular card authentication use case in Estonia.[9] To avoid the need for a separate smart card reader, the merchants tested in this study communicate with the ID card chip using the point-of-sale (POS) terminal. The support for ID card has been implemented in the firmware of the payment terminals, the merchant systems receiving only the predefined records of the personal data file. We found three payment terminal models that were used by Estonian merchants to communicate with ID card. These are: Ingenico iPP320 (Apollo, Apotheka, Grossi Toidukaubad and Olerex), VeriFone Vx805/Vx820 (Lido and Rahva Raamat) and Worldline YOMANI (K-Rauta and Prisma).

[8] Exceptions are the digital identity cards issued before 2014 which support T=0 only.

[9] For different reasons not all merchants in Estonia accept ID card as a loyalty card [24]. These merchants provide their own loyalty cards which are usually magnetic stripe cards or contactless chip cards [18].

Table 3. The results of using the ID card emulator in terminals deployed in practice

Terminal	Records read	ATR check	Protocol
Apotheka (PC reader)	first nine records	No	T=0 pref.
Ektaco ARGOS	doc. nr.	Yes	T=0 pref.
Ingenico iPP320	all records	Yes	T=0 pref.
National Library	all records	No	T=1 pref.
Pilveprint	doc. nr.	No	T=0 only
TUT library entrance	all records	No	T=1 pref.
TUT library checkout	ID code	Yes	T=1 pref.
VeriFone Vx805/Vx820	doc. nr., name, expiry date, ID code	No	T=0 pref.
Worldline YOMANI	ID code, doc. nr., expiry date	Yes	T=0 pref.

5.1 Apotheka (PC reader)

Apotheka pharmacy chain in Estonia unites more than 180 pharmacies under the Apotheka trademark. The ID card can be used as a loyalty card additionally to the magnetic stripe card offered by the merchant. Alternatively to the payment terminal, the ID card can be inserted in a separate smart card reader connected to the pharmacist's computer. When the card is inserted, the terminal in a nonconsecutive order reads the first nine records from the personal data file. It is odd to see that the first APDU sent to the card is `A0 A4 00 00 02 7F 20`, which is the `SELECT DF.GSM` command from the GSM standard. The APDU traces were collected in Apotheka pharmacies in Tartu.

Digital Prescription Lookup. The card reader connected to the pharmacist's computer is also used to automate the lookup of drugs prescribed to the patient in the digital prescription system [5]. In the prescription lookup process the cardholder's surname, first name (both lines) and the personal ID code is read from the personal data file. Afterwards the document number is read in a loop, probably to detect insertion of a new card. Like in the loyalty card's use case, ATR is not verified. However, the digital prescription lookup application establishes T=1 connection to the ID card.

We noted that contrary to the legal requirement, in the process of prescription lookup the pharmacist used our ID card emulator without asking for any physical identification document. However, even if a physical identification document would be verified, the identity read from the chip is likely not verified with the information printed on the card, hence the chip transplantation (Sect. 4.3) could allow to impersonate another person.

5.2 Ektaco ARGOS

The Estonian company Ektaco has developed the ARGOS-series access control system where the ID card can be used as a key. According to Ektaco, by using the DIP switch the system can be configured to authorize door unlocking either using the personal ID code or the document number of the ID card. The access control system does not have the capability to perform document expiry or validity checks. The APDU traces were collected from the unsupervised Ektaco terminals installed on the side gate of TTK University of Applied Sciences and the front door of Tudengimaja. As we can see from the traces, both access control systems are configured to use document number for authorization.

5.3 Ingenico iPP320

Ingenico iPP320 is a payment terminal with personal data file reading functionality implemented by company Voicecom OÜ. The payment terminal returns to the POS system all personal data file records read from the chip using PosXML protocol [36, Sect. 2.4.2]. Before reading the personal data file the terminal performs EMV application discovery process by sending EMV application selection APDUs to the card. We found the ID card reading functionality of the terminal to be used by merchants Apollo, Apotheka, Grossi Toidukaubad and Olerex.

Apollo is a cinema and bookstore chain with 10 stores in Estonia. Apollo in 2005 was the first merchant in Estonia to accept the ID card as a loyalty card [1]. The APDU traces were collected in the Apollo Lunakeskus bookstore in Tartu.

Grossi Toidukaubad is a grocery store chain with 54 stores over Estonia. The ID card can be used as a loyalty card alternatively to the magnetic stripe card offered by the merchant. The APDU traces were collected in Grossi Toidukaubad store in Tartu.

Olerex is an Estonian oil company having 80 fuel stations across Estonia. The ID card can be used as a loyalty card or as a credit card [27]. To register the ID card as a credit card, a credit agreement has to be digitally signed in the Olerex self-service portal. In the registration process the cardholder has to select a 4-digit PIN code that is stored in the Olerex payment system and has to be entered in the payment terminal whenever using the ID card as a credit card (before entering the PIN the ID card has to be removed from the terminal). The APDU traces for the ID card's use as a credit card and a loyalty card are the same. The APDU traces were collected in Olerex fuel station in Tartu.

5.4 National Library

The libraries in Estonia make a heavy use of ID card for client identification alternatively to barcode-based library cards [15]. The National Library of Estonia allows the use of the ID card as a library card [20]. When entering the library, the ID card has to be inserted in a card reader and the security guard checks on the screen if the person has registered as a reader and has the right to access the library.

5.5 Pilveprint

Pilveprint is a cloud printing service with public printing machines located in educational institutions and libraries all over Estonia. The documents to be printed can be uploaded in the Pilveprint self-service portal. To release and print the document, the user has to insert his ID card in the printing machine. Before being able to use the ID card in the printing machine, in the self-service portal the user has to manually bind the document number of his ID card to his Pilveprint user account. The APDU traces were collected from the printing machine located in the University of Tartu Lossi 3 building.

5.6 TUT Library

The library of Tallinn University of Technology uses the ID card as a library card. The card has to be inserted in the smart card reader when entering the library. The card insertion is supervised by the librarian and a different sound signal is made depending on whether the inserted ID card is accepted or not.

The library has also two self-checkout machines that can be used by the readers to borrow books. The ID card has to be inserted in the machine and then the barcode of the book can be scanned. The APDU traces were collected from the self-checkout machine located on the second (entrance) floor of the library.

5.7 VeriFone Vx805/Vx820

VeriFone Vx805/Vx820 is a payment terminal with personal data file reading functionality implemented by company Verifone Baltic SIA. The terminal does not perform ATR verification and EMV application discovery process is not visible in APDU traces. For this reason to read the ID card the POS system has to be switched to ID card reading mode. We found the ID card reading functionality of the terminal to be used by merchants Lido and Rahva Raamat.

Lido is a restaurant and bistro network with three restaurants in Tallinn. The APDU traces were collected in Lido Mustame Center restaurant.

Rahva Raamat is a bookstore chain with 10 stores in Estonia. The APDU traces were collected in Rahva Raamat Tasku store in Tartu.

5.8 Worldline YOMANI

Worldline YOMANI is a payment terminal with personal data file reading functionality implemented by Verifone Finland Oy. Before reading the personal data file the terminal performs EMV application discovery process. After that the card is reset and three records from the personal data file are read. We found the ID card reading functionality of the terminal to be used by merchants K-Rauta and Prisma.

K-rauta is a chain of construction and home furnishings department stores with eight stores located in Estonia. The ID card can be used as a loyalty card alternatively to the magnetic stripe card offered by the merchant. The APDU traces where collected in K-rauta store in Tartu.

Prisma is a hypermarket chain owned by SOK corporation with eight stores in Estonia. Prisma offers the biggest ID card-based loyalty program in Estonia which is estimated to be used by at least 150 000 customers. The ID card has to be inserted in the payment terminal. At the end of the EMV application discovery the terminal attempts to select an unknown AID FFFFFFFFFF0111. The terminal then tries to select AID A0000003790000 which corresponds to the AID of the Finnish S-Etukortti SOK loyalty card used in Finland. The insertion of the card that supports only the T=1 protocol causes the terminal to reboot after the EMV application discovery is performed. The APDU traces were collected in Prisma Sobra store in Tartu and self-checkout terminal of Prisma Kristiine store in Tallinn.

6 Discussion: Improvements

As demonstrated in the previous sections, the currently used chip authentication mechanism can be abused by a malicious cardholder to execute card impersonation attacks. The use of cryptographic capabilities provided by the current ID cards, while assuring the terminal, would make authentication and digital signature keys open to abuse by a malicious terminal (Sect. 3.3). In this section we discuss the possible technological improvements to the ID card that could improve the security and usability, therefore enabling wider use of ID card as a physical authentication token.

6.1 Cloning Prevention

To prevent the card impersonation attack, the card authentication process should verify that the unclonable private key objects are residing on the chip. To achieve this the terminal should require the card to sign some random challenge and verify it using the certificate. To prevent the abuse of the authentication or digital signature keys residing on the ID card, the ID card should contain a separate card authentication key and the corresponding certificate. The key should be used only for card authentication purpose and operable without requirement to enter a PIN.

The data in the personal data file or its hash should be embedded in the card authentication certificate to provide its integrity. The validity information of the card authentication certificate should correspond to the validity of the document, thereby enabling reliable document validity checking (Sect. 2.1). This chip cloning prevention feature is similar to FIPS 201-2 (PIV card) "card authentication key (CAK)" [21], and Active Authentication in ICAO ePassport [13]. The card authentication feature can be remotely deployed as an additional Java Card applet on the already issued ID cards. The use of a separate applet provides flexibility, since then the applet does not have to be Common Criteria certified, which is the requirement for applets that are used to create eIDAS-compatible QESs. To make use of the cryptographic feature the terminal owners will have to invest in adapting the terminal software. The software, however, to some extent will have to be updated anyway, since the new generation ID cards (planned to be issued starting 2019) will have a new ATR, and due to eIDAS certification requirements the EstEID applet will have to be replaced with the internationally developed IAS-ECC applet [23, slide 14] and it is not yet known if it will support the Estonian personal data file feature in its current form.

Performance. To evaluate the performance of the suggested card authentication feature, we performed measurements using two ID card generations in circulation – the chip of identity cards issued since 2011 and the newest generation chip issued in identity cards since October 2014. The results are shown in Table 4. To summarize, if the ECDSA is used, the cryptographic card authentication process takes around 1.5 seconds on ID cards issued after 2011, but only 0.6 seconds on the cards issued after October 2014. By utilizing the certificate caching mechanisms the time could be decreased to below 200 ms on the latest generation of ID cards. This would considerably improve the user experience when using the ID card as an entrance card.

Table 4. The performance of two ID card chip generations

Measurement	2011 (ms)	2014 (ms)
Reading personal ID code	150	150
Reading entire personal data file	625	450
Reading 1.5 KB certificate	440	380
RSA-2048 signing	1500	385
ECDSA with NIST P-256	1000	160

Relay Attacks. While the card authentication process would prevent the use of ID card forgeries, a more sophisticated relay attack where the fraudulent card relays card authentication commands to the legitimate card is still possible. The relay attacks are not trivial to prevent. The EMV contactless payment card specification tries to prevent them using distance bounding protocols, which are far from trivial to implement in the actual physical hardware [19].

The relay attacks to some extent are more applicable to universal credentials such as the ID card, since the terminal-specific authentification tokens are presented and hence accessible only to the owner of the terminal that issued the respective token.

6.2 Cardholder Verification

Verification Using PIN Code. A basic protection against unauthorized use of the ID card by a non-owner of the card can be implemented by requiring cardholder verification using an additional PIN3 code. In practice, however, the added security value may be too insignificant to compensate for the degraded user experience caused by entering and memorizing yet another PIN.

The entering of the PIN into a terminal and in an environment controlled by some third party would also greatly increase the risk of the PIN compromise. In the EMV payment card rollout in the U.S., banks have chosen to abandon PIN verification, because most of the fraud cases are caused by counterfeit cards, while the fraud due to lost and stolen cards being minimal [16]. The use of lost or stolen cards can instead be prevented by card revocation mechanisms.

The cardholder verification using the PIN code does not prevent the fraud where the owner of the card has authorized the use of his ID card by a non-owner of the card. In some fraud schemes (e.g., in some customer loyalty programs) the owner may have a direct or indirect interest in his card being used by the non-owner.

Verification Using Biometrics. To completely eliminate the use of the ID card by the a non-owner of the card, the identity of the card user would have to be verified. Due to the chip transplantation attacks (Sect. 4.3), not only the facial image printed on the identity document has to be verified, but also the personal ID code retrieved electronically should be compared with the personal ID code printed on the document. To automate the verification task as much as possible, the facial image of the cardholder should be stored on the card, indirectly signed by including its hash into the card authentication certificate. The person performing cardholder verification would then only need to compare the digital image retrieved from the chip with the facial features of the card user. This task in turn could be further delegated to a face recognition system.

A similar feature is already provided by the ePassport chip on the residence permit cards (see Sect. 3.1). Therefore, as an alternative to cryptographic improvements for the ID card chip, all types of ID cards could be equipped with ICAO ePassport chip. The advantage of this solution being that an internationally standardized method would be used for cardholder authentication, and in the case of the Estonian ID card, allowing the BAC key to be read from the contact chip without the need for optical character recognition. The disadvantage being that two readers are needed, which complicates the deployment and slows down the speed of card authentication transactions.

6.3 Contactless Interface

With the exception of residence permit card which contains separate contactless ICAO ePassport chip, the current ID cards in circulation do not have a contactless interface. The potential benefits for adding the contactless interface to the ID card has been discussed in [4,14]. A non-public pilot for using NFC-enabled digital identity cards with mobile phones has been described in [17,26].

While the traditional electronic use of ID card does not benefit much from the contactless interface (except perhaps to interface with mobile devices), the convenience provided by the contactless interface would be especially useful for the ID card's use as an entrance card, allowing the terminals to be made more vandal proof and making the process more convenient.

However, the introduced security risk is that cardholder identifiable information could be retrieved covertly from a distance, and the covert access to PIN-less card authentication key would make relay attacks easier to execute. The security risk could be largely solved by implementing an NFC antenna-enabling button on the card [29]. The cards with such buttons, however, are currently not available on the market. The U.S. Department of Defense, for example, has decided to enable contactless interface for CAC cards, but has issued radio frequency shielding sleeves to the cardholders [30].

7 Conclusion

We have shown the design of the ID card emulator which is able to impersonate a real Estonian ID card to the terminals deployed in practice. Building such an ID card emulator today is both feasible and affordable, therefore the current ID card chip authentication mechanism which does not involve any cryptographic assurance should not be used for high risk transactions. By demonstrating the reliability of ID card chip transplantation process, we have shown that the authenticity of data read from the chip should not be trusted even if the chip is part of a visually authentic ID card.

The study of terminals deployed in practice shows that the terminals do not perform document expiration and revocation checks, and most of the terminals read more personal data from the ID card than required for cardholder identification.

We hope that this paper will raise awareness of the risks with the current ID card chip authentication mechanism and will facilitate the development of a secure and universal authentication solution. Such a solution is highly needed in the current situation in Estonia where a variety of proprietary solutions vulnerable to cloning and replay attacks are ubiquitous [3,18].

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Appendix A: ID Card Chip Transplantation Process

(a) SmartCafe Expert 6.0 chip removal

(b) SmartCafe Expert 6.0 with chip removed

(c) ID card chip removal

(d) ID card chip partially removed

(e) ID card with chip glue residues

(f) ID card with chip removed

(g) Cards with the removed chips

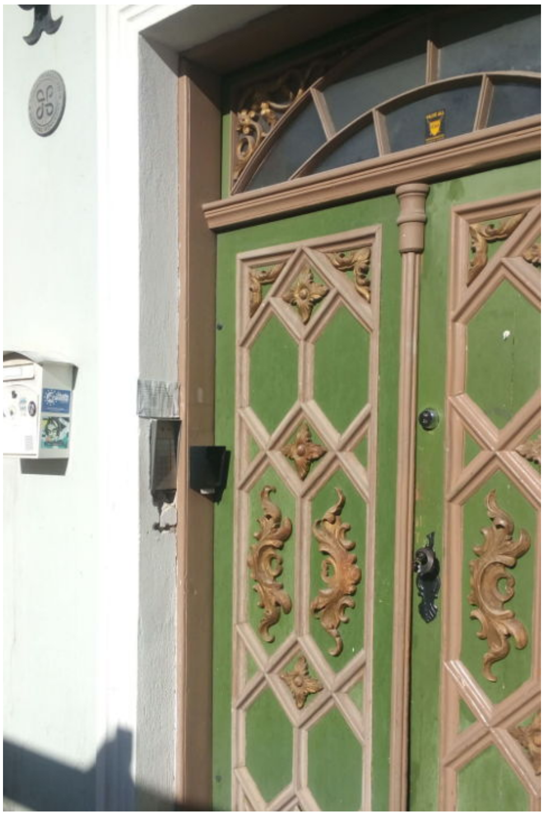
(h) Original (top) vs transplanted (bottom)

Fig. 4. Chip transplantation process

Appendix B: Some of the Terminals Tested in This Study

(a) Ektaco terminal (Prnu mnt 62, Tallinn)

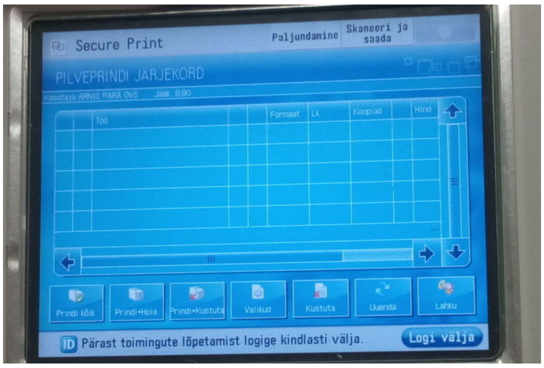
(b) Ektaco terminal (from inside area)



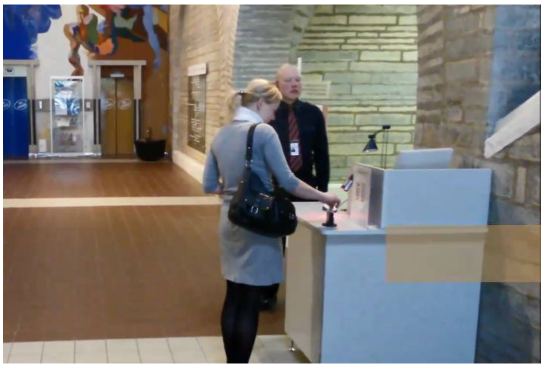
(c) Tudengimaja (Raekoja plats 16, Tallinn)

(d) Tudengimaja Ektaco terminal

(e) Pilveprint printer (Lossi 3, Tartu)

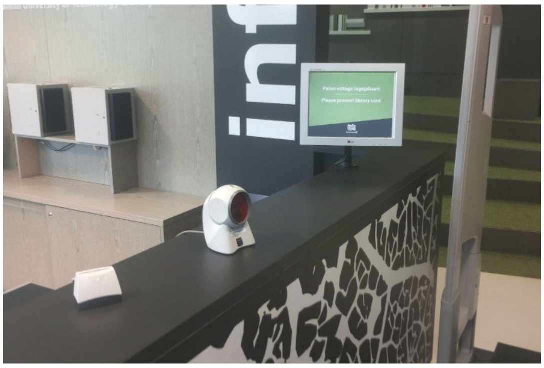


(f) Printer menu for authenticated user

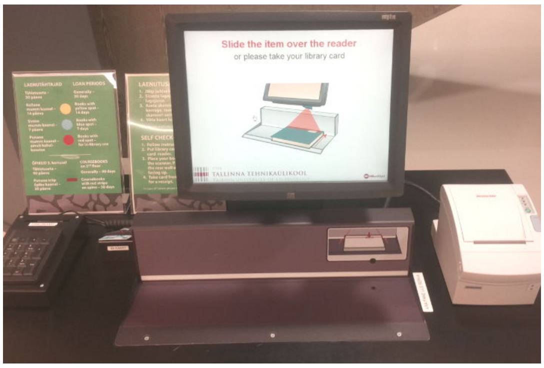


(g) National Library entrance (from [20])

(h) National Library entrance terminal



(i) TUT library entrance terminal



(j) TUT library self-checkout machine

Fig. 5. Some of the tested terminals

Appendix C: Collected APDU Traces

APDU trace 1.1. Apotheka PC reader (loyalty card reading)

```
T=0
A0 A4 00 00 02 7F 20
00 A4 00 0C 00
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 07 04 00
00 C0 00 00 0B
00 B2 09 04 00
00 C0 00 00 0A
00 B2 08 04 00
00 C0 00 00 09
00 B2 05 04 00
00 C0 00 00 03
00 B2 04 04 00
00 C0 00 00 01
00 B2 01 04 00
00 C0 00 00 07
00 B2 02 04 00
00 C0 00 00 05
00 B2 03 04 00
00 C0 00 00 01
00 B2 06 04 00
00 C0 00 00 0A
```

APDU trace 1.2. Apotheka PC reader (digital prescription lookup)

```
T=1
00 A4 04 00 0B A0 00 00 03 97 43 49 44 5F 01 00
00 CA 7F 68 00
00 A4 04 00 09 A0 00 00 03 08 00 00 10 00
00 A4 04 00 09 A0 00 00 03 97 42 54 46 59
00 A4 00 0C 00
00 A4 01 0C 02 EE EE
00 A4 02 0C 02 50 44
00 B2 01 04 1C
00 B2 02 04 0F
00 B2 03 04 0F
00 B2 07 04 0B
00 A4 00 08 00
00 A4 00 08 00
00 A4 01 08 02 EE EE
00 A4 02 04 02 50 44
00 B2 08 04 00
00 A4 00 08 00
00 A4 00 08 00
00 A4 01 08 02 EE EE
00 A4 02 04 02 50 44
00 B2 08 04 00
00 A4 00 08 00
```

APDU trace 1.3. Ektaco ARGOS

```
T=0
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 08 04 00
00 C0 00 00 09
```

APDU trace 1.4. Ingenico iPP320 (Apollo)

```
T=0
00 A4 04 00 0E 31 50 41 59 2E 53 59 53 2E 44 44 46 30 31
00 A4 04 00 06 A0 00 00 00 25 01
00 A4 04 00 07 A0 00 00 00 03 20 20
00 A4 04 00 07 A0 00 00 00 04 10 10
00 A4 04 00 07 A0 00 00 00 04 30 60
00 A4 04 00 07 A0 00 00 00 03 10 10
00 A4 04 00 07 A0 00 00 00 03 20 10
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 01 04 00
00 C0 00 00 07
00 B2 02 04 00
00 C0 00 00 05
00 B2 03 04 00
00 C0 00 00 01
00 B2 04 04 00
00 C0 00 00 01
00 B2 05 04 00
00 C0 00 00 03
00 B2 06 04 00
00 C0 00 00 0A
00 B2 07 04 00
00 C0 00 00 0B
00 B2 08 04 00
00 C0 00 00 09
00 B2 09 04 00
00 C0 00 00 0A
00 B2 0A 04 00
00 C0 00 00 0A
00 B2 0B 04 00
00 C0 00 00 0A
00 B2 0C 04 00
00 C0 00 00 01
00 B2 0D 04 00
00 C0 00 00 17
00 B2 0E 04 00
00 C0 00 00 13
00 B2 0F 04 00
00 C0 00 00 1C
00 B2 10 04 00
00 C0 00 00 0F
```

APDU trace 1.5. Ingenico iPP320 (Apotheka, Grossi Toidukaubad, Olerex)

```
T=0
00 A4 04 00 0E 31 50 41 59 2E 53 59 53 2E 44 44 46 30 31
00 A4 04 00 07 A0 00 00 00 03 10 10
00 A4 04 00 07 A0 00 00 00 03 20 10
00 A4 04 00 07 A0 00 00 00 03 20 20
00 A4 04 00 07 A0 00 00 00 04 10 10
00 A4 04 00 07 A0 00 00 00 04 30 60
00 A4 04 00 05 A0 00 00 00 25
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 01 04 00
00 C0 00 00 07
00 B2 02 04 00
00 C0 00 00 05
00 B2 03 04 00
00 C0 00 00 01
00 B2 04 04 00
00 C0 00 00 01
00 B2 05 04 00
00 C0 00 00 03
00 B2 06 04 00
00 C0 00 00 0A
00 B2 07 04 00
00 C0 00 00 0B
00 B2 08 04 00
00 C0 00 00 09
00 B2 09 04 00
00 C0 00 00 0A
00 B2 0A 04 00
00 C0 00 00 0A
00 B2 0B 04 00
00 C0 00 00 0A
00 B2 0C 04 00
00 C0 00 00 01
00 B2 0D 04 00
00 C0 00 00 17
00 B2 0E 04 00
00 C0 00 00 13
00 B2 0F 04 00
00 C0 00 00 1C
00 B2 10 04 00
00 C0 00 00 0F
```

APDU trace 1.6. National Library

```
T=1
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 01 04 1C
00 B2 02 04 0F
00 B2 03 04 0F
00 B2 04 04 01
00 B2 05 04 03
```

```
00 B2 06 04 0A
00 B2 07 04 0B
00 B2 08 04 09
00 B2 09 04 0A
00 B2 0A 04 23
00 B2 0B 04 0A
00 B2 0C 04 32
00 B2 0D 04 32
00 B2 0E 04 32
00 B2 0F 04 32
00 B2 10 04 32
```

APDU trace 1.7. Pilveprint

```
T=0
00 A4 01 04 02 EE EE
00 A4 02 04 02 50 44
00 B2 08 04 00
00 C0 00 00 09
```

APDU trace 1.8. TUT library entrance

```
T=1
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 01 04 1C
00 B2 02 04 0F
00 B2 03 04 0F
00 B2 04 04 01
00 B2 05 04 03
00 B2 06 04 0A
00 B2 07 04 0B
00 B2 08 04 09
00 B2 09 04 0A
00 B2 0A 04 23
00 B2 0B 04 0A
00 B2 0C 04 32
00 B2 0D 04 32
00 B2 0E 04 32
00 B2 0F 04 32
00 B2 10 04 32
```

APDU trace 1.9. TUT library self-checkout

```
T=1
00 A4 00 0C 80
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 07 04 00
```

APDU trace 1.10. VeriFone Vx805/Vx820 (Lido, Rahva Raamat)

```
T=0
00 A4 04 0C 0F D2 33 00 00 00 45 73 74 45 49 44 20 76 33 35
00 A4 00 0C 00
```

```
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 08 04 00
00 C0 00 00 09
00 B2 02 04 00
00 C0 00 00 05
00 B2 01 04 00
00 C0 00 00 07
00 B2 09 04 00
00 C0 00 00 0A
00 B2 07 04 00
00 C0 00 00 0B
```

APDU trace 1.11. Worldline YOMANI (K-Rauta)

```
T=0
00 A4 04 00 0E 31 50 41 59 2E 53 59 53 2E 44 44 46 30 31
00 A4 04 00 07 A0 00 00 00 03 10 10
00 A4 04 00 07 A0 00 00 00 03 20 10
00 A4 04 00 07 A0 00 00 00 03 20 20
00 A4 04 00 07 A0 00 00 00 04 10 10
00 A4 04 00 07 A0 00 00 00 04 30 60
CARD RESET
T=0
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 07 04 00
00 C0 00 00 0B
00 B2 08 04 00
00 C0 00 00 09
00 B2 09 04 00
00 C0 00 00 0A
```

APDU trace 1.12. Worldline YOMANI (Prisma)

```
T=0
00 A4 04 00 0E 31 50 41 59 2E 53 59 53 2E 44 44 46 30 31
00 A4 04 00 07 A0 00 00 00 03 10 10
00 A4 04 00 07 A0 00 00 00 03 20 10
00 A4 04 00 07 A0 00 00 00 03 20 20
00 A4 04 00 07 A0 00 00 00 04 10 10
00 A4 04 00 07 A0 00 00 00 04 30 60
00 A4 04 00 07 FF FF FF FF FF 01 11
00 A4 04 00 07 A0 00 00 03 79 00 00
CARD RESET
T=0
00 A4 01 0C 02 EE EE
00 A4 02 04 02 50 44
00 B2 07 04 00
00 C0 00 00 0B
00 B2 08 04 00
00 C0 00 00 09
00 B2 09 04 00
00 C0 00 00 0A
```