Digital Voting Pass

One step towards the digitalization of the entire voting process

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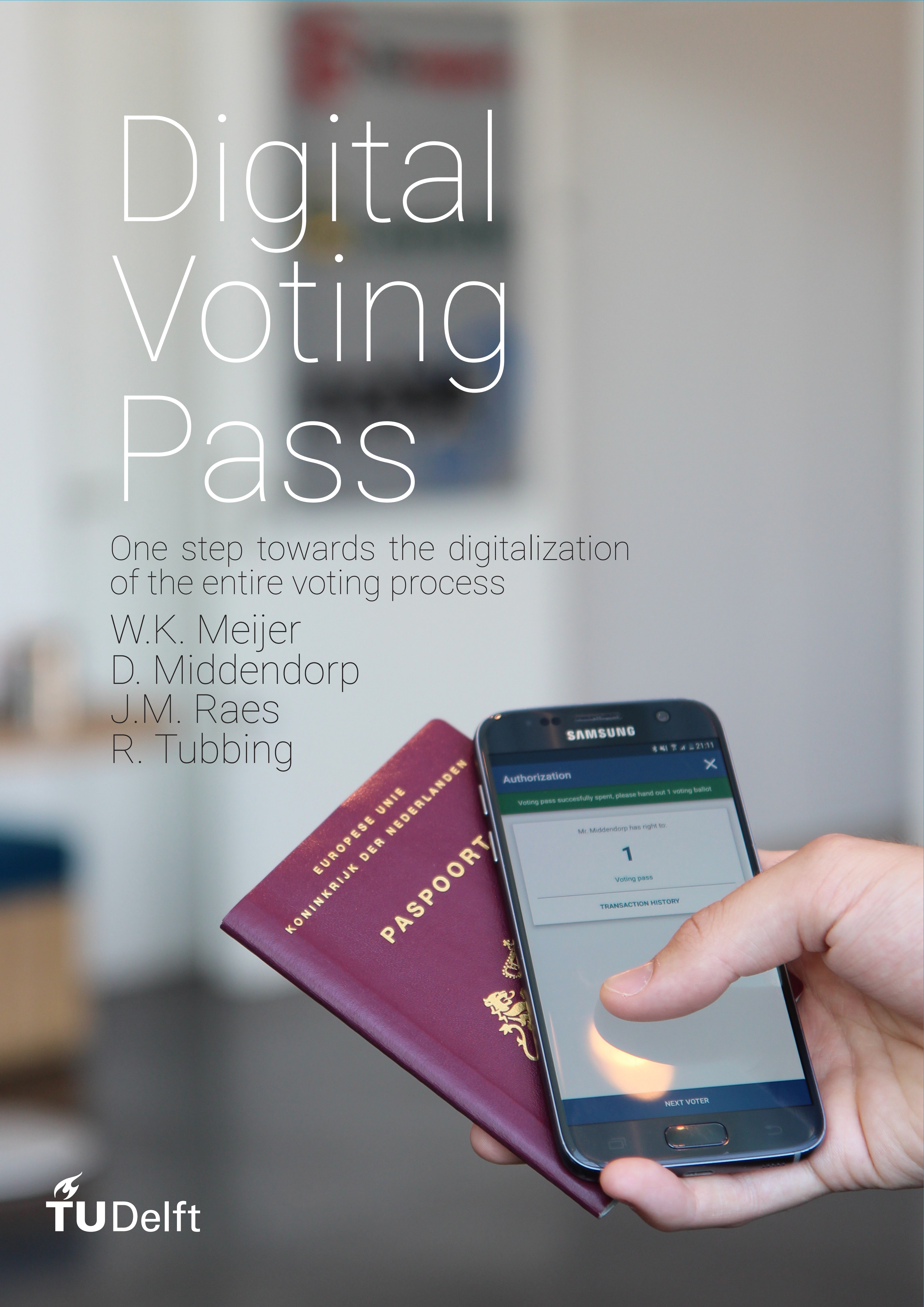
EUROPESE UNIE
KONINKRIJK DER NEDERLANDEN
PASPOORT
SAMSUNG
21:11
Authorization
Voting pass succesfully spent, please hand out 1 voting ballot
Mr. Middendorp has right to:
1
Voting pass
TRANSACTION HISTORY
NEXT VOTER

TUDelft

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One step towards the digitalization of the entire voting process

by

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Summary

The Dutch electoral voting system is designed in a way that does not fit in the current era of the digital transformation. Almost every procedure during the elections is done manually and cannot differ from the policy prescribed by Dutch law. For example, the type of paper used for the ballot paper and the dimensions of a voting booth are both defined by a section in the election law.

This thesis aims to investigate a more trustworthy, transparent and less expensive way of verifying the suffrage of a citizen. A literature review is presented about the election process in other countries and new possibilities with state of the art technology. Based on these investigations, a solution — built with blockchain and machine readable travel documents — that would make the current voting pass superfluous is presented.

The technology of blockchain arose back in 2009, when it was used as the underlying network of the Bitcoin cryptocurrency. A blockchain is a decentralized list of transactions, where every transaction is immutable and built following predefined rules. These transactions are visible and verifiable for anyone connected to the decentralized network.

Dutch travel documents (passports, identity cards and driver's licences) are designed according to the ICAO machine readable travel document standard, which also requires the presence of a biometric chip. This means that every citizen already has access to a PKI (public key infrastructure) keypair, which can be used to sign data.

The presented solution combines these technologies and is first of its kind to link a machine readable travel document to a blockchain. All kinds of organizations struggling with the identity problem can expect to benefit from these new possibilities.

Contents

1 Introduction

In the Netherlands, there have been different types of voting processes over the past couple of years. From mechanical machines in the late ’60s and electrical machines in the late ’70s to digital voting computers since the early ’90s. These last non-transparent solutions evoked a lot of resistance by skeptical parties[1], which makes sense in this era of cyber-warfare. Due to this skepticism and distrust, the cabinet decided to return to the pencil and paper variant in 2009 [2].

Strong call for digital systems
The return to digital to paper voting brings a lot of manual work and extra costs. It requires much effort from volunteers at the polling station, who need to tally the votes by hand till the early morning. Because of this, there is a strong call for any technology that can help these municipalities in making the elections easier to organize from a practical point of view.

The rise of blockchain
Satoshi Nakamoto built the first practical application, a peer-to-peer digital cash system called Bitcoin, on technology now known as blockchain. Since this innovation there have been a lot of experiments performed using this technology [3]. A blockchain is a decentralized ledger of transactions, where every transaction is immutable and built following predefined rules. These transactions are visible and verifiable for anyone connected to the decentralized network. This makes it well suited for applications where trust is a central subject. As of today, experiments with blockchain are studied in a wide range of fields, from electric vehicle charging stations to medical records and currencies [4–6].

Machine readable travel documents
Since August 2006, Dutch travel documents are equipped with an ePassport chip [7]. These biometric chips are designed according to the ICOA standard of machine readable travel documents and provide every citizen with technological advanced tools to prove their identity. This chip is compatible with widely adopted RFID standards which comes with the benefit that it can be read by an average Android smartphone.

One of these tools to ensure an identity, is the presence of an elliptic curve public key infrastructure (PKI) mechanism, which consists of a private and public key stored onto the chip. The private key is generated inside the travel document and cannot be read from the outside. This ensures that it is, with the current technology, impossible to make an exact clone of the e-passport chip. Contrary to the private key, the public key can be read directly from the chip. Furthermore, a signing function is present in the chip, which can be used to sign data with the embedded private key.

Research statement
The purpose of this research is to investigate the possibilities and importance of technological advancements in the elections of a democracy. The aim is to prove that there are digital solutions which enhance the entire process while getting the trustworthiness of voting at an improved level. With all the future proof interfaces, like the possibility to store an iris scan, provided in government issued id’s and the rise of blockchain based systems, the results from this study will demonstrate the important role of transparent technology in this identity problem.

This results in the main research question of this thesis:

How can the paper voting pass in the Dutch voting system be replaced by a secure, trustworthy, and easy-to-use digital system?

This research question is split up into the following sub-questions:

- How does the current Dutch (paper) voting process work?
- What are existing digital voting systems and how do they work?
- How to keep track of the identity of the voter?
- How to ensure that an individual cannot vote more than once?
- How to ensure the process cannot be manipulated by external parties?
- How to allow proxy-voting?
- How can we make the process trustworthy to skeptics?

Methodology

The analysis will be based on a functional prototype of a digital voting pass. This prototype is built by adopting and forking different specific libraries and systems to create a standalone voting ecosystem which is compatible with the cryptography used in the biometric chip of Dutch travel documents.

This ecosystem consists of three applications:

Polling station app
: An Android application to verify and redeem the suffrage on the blockchain using a machine readable travel document.

Voter helper app
: An Android application to transfer the suffrage to someone else using two machine readable travel documents.

EPassportChain utility
: A simple command line utility to organize an election by importing a CSV-file containing all the public keys of the citizens eligible to vote.

To test and develop the connection with the ePassport chip, a specimen set of a passport and an identity card is provided by the Ministry of the Interior and Kingdom Relations, which are fully compatible with travel documents issued after March 9, 2014.

Thesis structure

The chapters of this thesis are structured in a way that corresponds largely with the actual process in chronological order. In chapter 2, the actual problem that this research is working on is described and analyzed. The first sprint where the passport interaction and blockchain was implemented, is described in chapter 3. The second sprint where the implemented technologies are connected can be found in chapter 4. The last sprint, creating the full working prototype, is discussed in chapter 5. To measure the scalability and performance, multiple tests are performed which results can be found in chapter 6. To keep track of the quality of the code, several steps are taken, which are described in chapter 7. The social impact is taken into account in chapter 8. At the end, this thesis concludes the research in chapter 9.

2 Problem description & analysis

General intro

2.1. Carelessness and fraud

In the Netherlands, recent decades have seen the introduction and farewell of multiple paper and digital voting systems. They all had their pros and cons in terms of trustworthiness and ease of use. As for most systems, they are not 100% airtight, which is too much to ask. A more important question is: will its flaws affect the final outcome and is this system acceptable in terms of ease of use?

Paper voting

The return of the ballot paper has not been flawless. During the last parliament elections written out by the Dutch government in 2017 several anomalies occurred. In one municipality votes went missing due to human error while entering the results[1] and the method used for letting people vote abroad did not arrive on time, making it impossible to vote for them[2].

These issues are an indication that manual work will not always ensure a trustworthy election. According to a statement by the political government office, these differences did not affect the final outcome. However, the investigations are not finished at the time of writing.

Digital voting

The types of mistakes stated above, which mainly relate to carelessness, are not really an issue with digital solutions. However, digital voting solutions are proved more vulnerable to fraud. The Dutch "We do not trust voting computers" foundation did a security analysis of the voting computers used by 90% of the Dutch municipalities until 2008. Their results were not satisfying at all [1].

For example, the physical lock system, which should protect the system from unauthorized usage, is a complete fallacy. Every key used across the country is identical and everyone is able to order those keys online in a webshop. The software used on those machines is even worse: the research proved that it is possible to modify the software of the voting computer by unscrewing it and replacing a memory component. First they managed to install chess on the voting computer, followed by a “fraud” version of the voting system application. This fraud version was able to cast random extra votes to a fraudulent party, without anything suspicious happening.

These results were taken seriously by the Dutch government and because of this, the parliament decided to get rid of the voting computers. The ballot paper returned in 2009.

2.2. Ease of use and efficiency

A few weeks in advance of election day it is the task of the Dutch municipalities to organize the elections. This task consists out of setting up the polling stations and making sure that every citizen eligible to vote, receives his or her voting pass.

[1]`http://nos.nl/artikel/2176913-7600-stemmen-boxmeer-niet-meegeteld-bij-de-verkiezingen.html`
[2]`http://nos.nl/artikel/2163145-stemmen-vanuit-buitenland-blijft-probleem.html`

The logistical operation of delivering 13 million voting passes to every citizen eligible to vote is a great challenge. It is highly dependent on the current postal infrastructure, which is a costly and time-consuming process.

On election day the voter needs to bring two items to the polling station: a voting pass and an identity document. These documents are checked at the polling station by an official who is assigned by the municipality.

Especially the paper voting pass leaves room for improvement. In the current process, the voting pass is inspected only visually. The officials are trained to verify the authenticity of the voting pass by looking at several authenticity marks [8]. Anyone with access to a printer capable of creating those authenticity marks can reproduce the voting pass and vote more than one time at different polling stations.

After the polling station is closed, the ballot papers and voting passes are counted manually. One of the most annoying parts of this step is when the amount of ballots and amount of voting passes do not match. If this is the case, every count needs to be done over and over until the numbers add up. Not having to count the voting passes at the end of the day will make the job more efficient and will cut the time needed to determine the final outcome.

2.3. Willingness to vote

The new generation Z, with birth years ranging from the mid-1990s to early 2000s has been exposed to an unprecedented amount of technology in their upbringing [9]. This generation is currently reaching the voting eligible age. In a decade where it is possible to order a pizza by talking to artificial intelligence [10], it is hard to explain an old fashioned way of voting to a new generation. Why should they visit a primary school building several blocks away to handle some paperwork? However, there does not seem to be any research available to endorse this effect on the willingness to vote.

2.4. Design criteria

The rest of this thesis will focus on applicability of blockchain technology for the election process. The system will have to be an open and transparent process which cannot be altered by other parties. The fundamental idea is that the proposed solution should more trustworthy than the current one.

In order to achieve this, great care should be taken in order to ensure the system cannot be influenced from outside. Besides the requirements related to confidentiality, the system should improve the experience of the current process. In other words: voting should become a more joyful experience and must comply with the current standards in terms of appearance.

In the near future, the design can be applied by any other party struggling with the identity problem. In fact, the voting pass is only a method to prove the authorization of someone to vote. This will introduce new a wide range of other applications, where it is desired to check the authorization or commit the actions performed by an individual, which might benefit from these new possibilities. E.g. it can be used as an entrance ticket to a concert or the registration of a blood donor.

3 Passport interaction and Blockchain implementation

The first sprint after the research phase was used for creating an initial prototype. This sprint had a duration of only one and a half weeks so the next sprints could start on a Monday.

The prototype consists of two parts:

- Creating an app that can interact with a travel document
- Altering a blockchain implementation so it works with a travel document

The focus of this sprint was to make clear if the proposed solution would be viable. Getting MultiChain to work with the passport was a concern and had to be implemented in this first sprint, otherwise another (less preferred) blockchain implementation had to be chosen to ensure the viability of the project.

3.1. Blockchain implementation

general intro

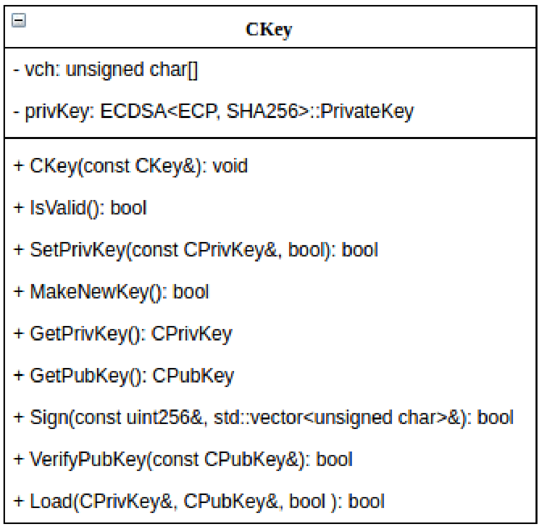
3.1.1. Multichain

MultiChain is a blockchain which is based on the Bitcoin core, but the developers of MultiChain have introduced additional features. It features a customizable permission system, where each node can have the following permissions: connect, send, receive, issue, create, mine, activate and admin [11]. The permissions send, receive, issue and mine are the most valuable for the initial prototype. The following list elaborates what an address is allowed to do:

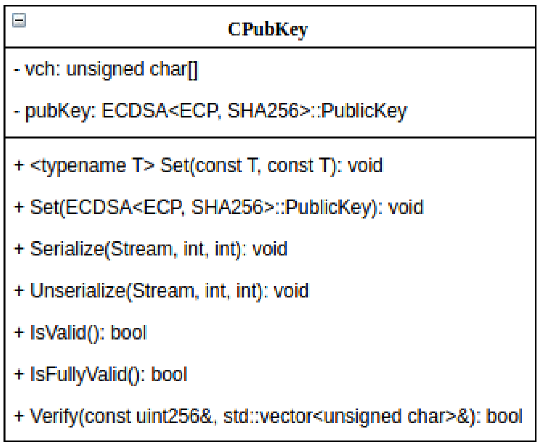
- send - The address is allowed to send tokens
- receive - The address is allowed to receive tokens
- issue - The address is allowed to create a new token
- mine - The address is allowed to mine

Sending and receiving are valuable permissions since every voter has an address which has one or more voting tokens, which represents if a voter is eligible to vote. Before an address can receive a token, it must have receive permissions. This way the is in control who receives voting right. A person can only claim his or her voting right when its address is has permissions to send a transaction.

The mining permission is valuable, since a third party could perform a monopoly attack (51% attack) only if it can construct a chain (and therefore mine new blocks). Since only addresses with mining permissions can create a block and thus expand the chain, a monopoly attack is not possible. Besides this, it is possible to alter the time it takes to mine a block, which is useful since transactions should be verified in at least 20 seconds (see requirement 3 in section A.1).


CKey
- vch: unsigned char[]
- privKey: ECDSA<ECP, SHA256>::PrivateKey
+ CKey(const CKey&): void
+ IsValid(): bool
+ SetPrivKey(const CPrivKey&, bool): bool
+ MakeNewKey(): bool
+ GetPrivKey(): CPrivKey
+ GetPubKey(): CPubKey
+ Sign(const uint256&, std::vector<unsigned char>&): bool
+ VerifyPubKey(const CPubKey&): bool
+ Load(CPrivKey&, CPubKey&, bool): bool

(a) Class diagram of CKey


CPubKey
- vch: unsigned char[]
- pubKey: ECDSA<ECP, SHA256>::PublicKey
+ <typename T> Set(const T, const T): void
+ Set(ECDSA<ECP, SHA256>::PublicKey): void
+ Serialize(Stream, int, int): void
+ Unserialize(Stream, int, int): void
+ IsValid(): bool
+ IsFullyValid(): bool
+ Verify(const uint256&, std::vector<unsigned char>&): bool

(b) Class diagram of CPubKey

Figure 3.1: Class diagrams of CKey and CPubKey

BrainpoolP320r1 implementation

MultiChain and most of the other blockchain technologies are using the secp256k1 elliptic curve to verify and sign transactions. This is mainly because of the performance of that curve, as stated in chapter 6. Since travel documents use the brainpoolP320r1 elliptic curve, a library that implements the brainpoolP320r1 elliptic curve is desired. CryptoPP[1] has implemented this curve and has been used to alter MultiChain to support brainpoolP320r1. From now on the modified version of MultiChain will be called ePassportChain.

The initial step to implement brainpoolP320r1 in ePassportChain was to find where the private and public keys are stored. After some searching in the code it was discovered that the private and public key are stored in the classes `CKey` and `CPubKey` respectively. These classes have been modified so MultiChain uses brainpoolP320r1 instead of secp256k1. The class diagrams of `CKey` and `CPubKey` are visualized in Figure 3.1a and Figure 3.1b respectively.

Originally, MultiChain stored the keys in the variable `vch`. In ePassportChain the variable `vch` contains the raw key (in both classes), while `privKey` and `pubKey` are the representation, in CryptoPP, of a private and public key respectively. The variable `vch` is still present in the implementation of ePassportChain since some functions require the raw keys as input our output. To be specific, in the class `CKey` the function `GetPrivKey` has as output a raw key (the type `CPrivKey` is a vector of unsigned chars with a secure allocator), while `SetPrivKey` and `Load` require as input a `CPrivKey`. In the class `CPubKey`, the functions `Serialize` and `Unserialize` has as in/output a raw key.

The next step was to modify the `Sign` and `Verify` functions, so that transactions can be signed and verified with brainpoolP320r1. This was quite easy since CryptoPP provides functionality to sign and verify hashes.

Travel document signing

Since a travel document can only sign eight bytes of data and the hash of a transaction is a SHA256 hash, which is 32 bytes long, the hash is split up in four different parts and are signed individually by a travel document. In Figure 3.2 a visualization of the signing by the passport is given, where the 32 byte block is the hash of a transaction.

As a consequence, ePassportChain must verify a transaction signed by a travel document, so the `Verify` function must be altered in such a way that it accepts four signatures. Initially, this caused some trouble since MultiChain implemented a maximum signature length of 255 bytes while one signature from a travel document is always 80 bytes long (so $4 * 80 > 255$). The 255 byte limit has been altered to support signatures of maximum 320 bytes long. This makes is possible to store the signatures after each other in a byte array, as is visualized in Figure 3.3. So for example, the signature of the second part of a hash, sig_1, is stored at index 80 until 160 of the byte array containing all signatures. The verify function now verifies each sig_i and if one of the signatures is incorrect the entire transaction is rejected.

[1]`https://www.cryptopp.com/`

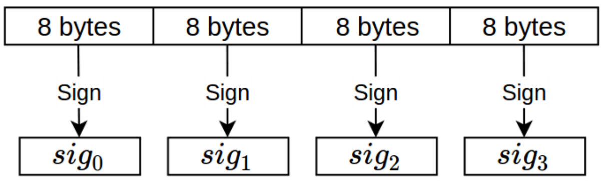


Figure 3.2: Signing a transaction with a travel document

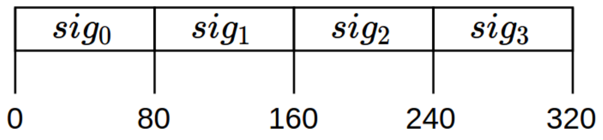


Figure 3.3: Signature storage

The problem now is that mined blocks create one signature of the hash, while the verification expects four signatures. Two options were considered:

- Choose the appropriate way to verify based on whether we are dealing with a block or transaction
- Sign the mined blocks in the same way as transactions, using 4 signatures

The second option was chosen, since it is easier to implement. The block-hash, like transactions, is split up in four parts, as displayed in Figure 3.2. These signatures are then stored as in Figure 3.3 so the verify function accepts these signatures. The first option is more secure and will be implemented in one of the following sprints.

Public key to blockchain address

To ensure that a machine readable travel document can act as a wallet, the public key of the document needs to be translated to an address on the blockchain. EPassportChain uses an address system similar to the one used in Bitcoin[12]. The small differences consist of the addition of an identifier generated by the blockchain instance itself. This value is hashed into the final address. Due to this, it is impossible to use an address which is intended for a different blockchain.

The steps leading to a valid address are well documented in the developer reference. This ensured a smooth integration of this process which led to a method to translate the public key of a passport to a valid address on the blockchain.

Distributing voting tokens

For every election, there needs a new batch of voting tokens to be sent to the citizens. For this first prototype, a simple python command line interface (CLI) script was built. This script follows the steps below:

1. Load CSV with public keys
2. Convert public keys to valid ePassportChain addresses
3. Create new assets corresponding to the amount of addresses
4. Grant send and receive permissions to the generated addresses
5. Distribute the assets to the generated addresses

This script can be found in the *e-passport-chain-util* repository[2].

3.1.2. Alternatives

Due to minor struggles during the implementation of the brainpoolP320r1 elliptic curve in MultiChain, other solutions are also considered during this sprint. One of the drawbacks of MultiChain is that it is built on the original Bitcoin core which is written in C++. This language makes it harder to understand the complex structure of a blockchain. The other possibilities that are considered are listed below.

[2]`https://github.com/digital-voting-pass/e-passport-chain-util`

Dragonchain
Dragonchain is a blockchain platform which is actively developed by the Walt Disney company, it does not seem to be entirely finished. It is written in Python which makes the code very accessible. The structure of a transaction relies on an embedded public key in PEM format. This means that the curve parameters are shipped with every transaction. Due to this, it does not matter which Elliptic Curve is used for the signing of a transaction. It literally took 5 minutes to come up with a proof of concept by modifying the unit test to a brainpoolP320r1 curve.

Unfortunately, Dragonchain is more some sort of blockchain platform, which only has support for raw transactions and Python based smart contracts. There does not seem to be any implementation of a wallet or any other way to store any value in the blockchain, just pure signed transactions.

Due to this, and the lack of documentation, this platform does not seem to be suitable for the purpose of implementing a digital voting pass.

Openchain
Another possible implementation is Openchain, which acts more like blockchain as a service. Because of this, there can only be one validation node, as discussed in Appendix E. The code is written in C# which makes it quite accessible. The only drawback of C# is that it is Microsoft-minded and you need the full DotNet framework to get it working.

The implementation uses the Bouncycastle library for signing and validation of transaction signatures. Due to this, it was relatively easy to transform the codebase to brainpoolP320r1. This transformation consisted out of changing the curve properties which are sent to Bouncycastle.

Different experiments turned out that is is fairly easy to issue a new assets as an admin and distribute it to an address. It was also quite simple to transform the public key of a passport to a valid Openchain address.

Further investigation of this solution was stopped because significant process was booked with the first-choice blockchain solution (Multichain).

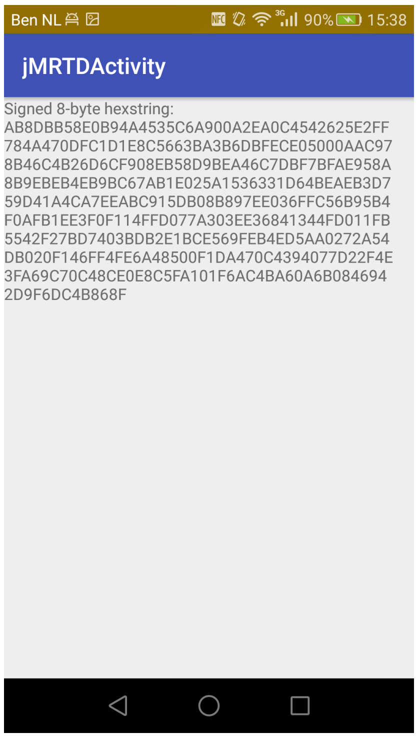
3.2. Alternative signing
Intro

3.2.1. Block ciphers modes of operation
As discussed in Appendix E, there is an issue with the capabilities of the travel document standard. This makes it impossible to sign a message larger than 8 bytes. So, it is difficult to sign a transaction which is hashed with a SHA256 hash, and has a length of 32 bytes. This problem is also relevant in other fields of cryptography, for example the 3DES encryption is only able to encrypt blocks of 8 bytes. To tackle this problem there are mainly two methods of operation to avoid this issue.

The first method is ECB (Electronic Code Book), named after the analog lookup books for encrypting and decrypting texts [13]. With this method, every single block of 8 bytes is encrypted and decrypted separately. Because 3DES is deterministic, which means that encrypting the same data with the same key results in the same cyphertext, blocks which contain the same data will also have the same cyphertext. Due to this, it becomes easy to find patterns in the encrypted data. Furthermore, it makes it also possible for an attacker to combine different blocks and create a complete new signed/encrypted message by using blocks from other encrypted messages. This is not that big of a problem, because the only thing that will be signed in this prototype is a SHA256 hash, which makes it difficult to combine different parts.

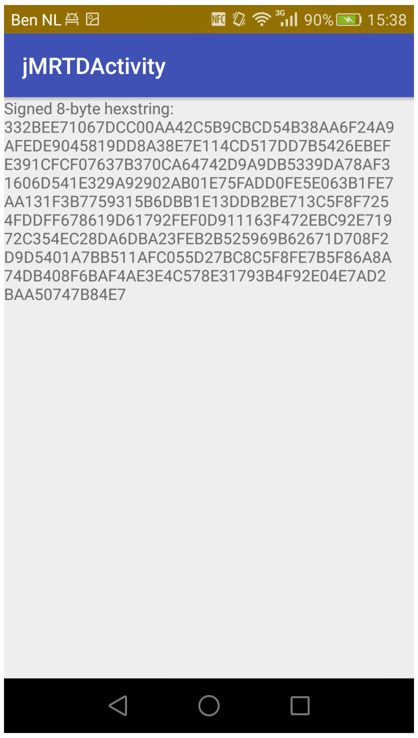
The second a method is called CBC (Cipher Block Chaining). Just like the blockchains in the rest of the prototype, this method consists of using previous blocks to sign or encrypt the upcoming blocks. This makes it more difficult to see patterns in the data which seems to be a clever idea, because it isn't even possible to determine the signature of a block if the signature of the previous block is unknown. Unfortunately, this method uses the previous signature to XOR the following block. The signatures created by a Dutch travel document are signed using ECDSA. Due to the possible leak of the private key, these signature are not deterministic which means that signing a block with the same travel document multiple times, results in a different signature every time. So encrypting an decrypting the next block using XOR will not work.

3.3. Coupling android app and passport
For both the Polling Station App and the Voter Helper App a connection with the passport needs to be made. This connection needs to accomplish two things:



```
Signed 8-byte hexstring:
AB8DBB58E0B94A4535C6A900A2EA0C4542625E2FF
784A470DFC1D1E8C5663BA3B6DBFECE05000AAC97
8B46C4B26D6CF908EB58D9BEA46C7DBF7BFAE958A
8B9EBEB4EB9BC67AB1E025A1536331D64BEAEB3D7
59D41A4CA7EEABC915DB08B897EE036FFC56B95B4
F0AFB1EE3F0F114FFD077A303EE36841344FD011FB
5542F27BD7403BDB2E1BCE569FEB4ED5AA0272A54
DB020F146FF4FE6A48500F1DA470C4394077D22F4E
3FA69C70C48CE0E8C5FA101F6AC4BA60A6B084694
2D9F6DC4B868F
```

(a) Output 1



```
Signed 8-byte hexstring:
332BEE71067DCC00AA42C5B9CBCD54B38AA6F24A9
AFEDE9045819DD8A38E7E114CD517DD7B5426EBEF
E391CFCF07637B370CA64742D9A9DB5339DA78AF3
1606D541E329A92902AB01E75FADD0FE5E063B1FE7
AA131F3B7759315B6DBB1E13DDB2BE713C5F8F725
4FDDFF678619D61792FEF0D911163F472EBC92E719
72C354EC28DA6DBA23FEB2B525969B62671D708F2
D9D5401A7BB511AFC055D27BC8C5F8FE7B5F86A8A
74DB408F6BAF4AE3E4C578E31793B4F92E04E7AD2
BAA50747B84E7
```

(b) Output 2

Figure 3.4: Results of signing the hex string '0a1b3c4d5e6faabb' with a passport

- Read the Active Authentication (AA) public key (located in Data-group 15 [14])
- Sign a blockchain transaction using the private key located in the passport

The AA public key serves as an identifier for the account of the voter on the blockchain. For every interaction (e.g. sending tokens, retrieving current balance) with the account of a voter, its public key is needed. To ensure that a transaction is performed with the authorization of the voter, the transaction needs to be signed with the voters' travel document.

The signing is done by making use of the AA protocol. This protocol serves as a verification of the uniqueness of the travel document. It accepts an 8-byte input and signs this with the private key of the travel document located in a non-readable part of the chip. The travel document returns a byte array containing the signature. It can be verified that this byte array was signed using the travel document belonging to a certain public key, confirming the authorization of the voter.

For creating the connection with the passport the JMRTD library[3] is used. JMRTD is an open-source java library that implements the MRTD (Machine Readable Travel Documents) standards as defined by the International Civil Aviation Organization (ICAO). The use of this library makes the connection in an Android app much easier since there is no need for a custom built interpretation layer between two programming languages.

In the Google Play Store a few apps can be found that make a connection with the passport and retrieve information from it. These apps give a clear example of a working concept. A well-known app is ReadId[4] which also makes use of the JMRTD library, this app unfortunatily is not open source. As a starting point the epassportreader app by github user Glamdring[5] was used, which has a very basic implementation of the JMRTD library.

The activity that reads the data from the passport waits until a NFC chip is detected, if this NFC chip belongs to a passport it tries to make a connection. For this connection three pieces of information are needed:

- Document number

[3]http://jmrtd.org/
[4]https://www.readid.com/
[5]https://github.com/Glamdring/epassport-reader

- Date of birth
- Expiry date of the document

This is needed for the Basic Access Control (BAC), which ensures a person trying to read the passport also has physical access to it. This information can be read from the Machine Readable Zone on the passport by using OCR as explained in section 3.4 or can be filled in manually when OCR fails or if OCR is not preferred by the user. Once the BAC succeeds, a connection is established and the contents of the chip are unlocked and can be read.

Depending on what functionality is needed one of these functions can be called:

- `getAAPublicKey()` - which returns the public key located in datagroup 15
- `signData()` - which accepts an 8-byte array as input and returns a byte array signed by the passport

In Figure 3.4 the resulting byte array represented as a hex string can be seen, since the signing algorithm of the passport is non-deterministic, the same input will yield different outputs every time.

These two functions are essential for signing transactions and getting information from the blockchain associated with the voter. The implementation of this functionality is described in chapter 4 and chapter 5.

3.4. Optical Character Recognition

There are a few options to choose from when it comes to performing optical character recognition (OCR) on an Android device. Two popular libraries that were considered are the Mobile Vision API [15], provided by Google, and Tesseract [16], which is also maintained mostly by Google. Tesseract has a history of being an accurate OCR solution, and it has an Android implementation called Tesseract Tools [17].

We chose to implement Tesseract and not Android Vision because first of all, looking at the vision example project, there was little support as issues were not being addressed. Next to this, after some testing it seemed that the Android Vision library is much less accurate than Tesseract and has no support for putting constraints on the detected data. Some people online seemed to switch to Tesseract after not reaching their goal with the Vision API. Therefore it was decided to go with Tesseract straight away, and more specifically, with tess-two [18], a fork of Tesseract Tools that is expanded and maintained. Because of the API 21+ requirement, (see requirement 6), only supporting the improved “android.hardware.camera2” camera API is required, these classes were introduced by Google in API 21 [19]. To make implementation easier and not reinvent the wheel, a sample app made by Google was used to get the code related to using the camera2 API [20].

During the development of the OCR feature, it was discovered that the speed of detection and the ability to run multiple scanning threads simultaneously is greatly dependent on the kind of phone used. For example, the Samsung Galaxy S7 and Google Pixel we used for testing had no difficulty running at least 4 threads and is able to scan a passport or ID card almost instantly. However, scanning on a LG G4 and a Galaxy S3, being older phones, was more difficult. Those phones started visually lagging when multiple scanning threads were started. Of course optimization of the OCR feature is still possible, which could slightly improve detection speed and accuracy. Since OCR is a CPU intensive operation this problem will only to diminish in the future given that the technology improves.

Surprisingly, the accuracy of the OCR is greatly dependent on the used document. One passport’s MRZ might be scanned instantly while scanning another might cost a lot of effort. This may be because of a different contrast on the older passports or because of the particular order of letters in the machine-readable zone. In particular, characters like 0, *O* and *D* or 8 and *B* are often wrongly interpreted. It is possible to write a piece of code that swaps known wrongly-interpreted characters, but this would involve checking many combinations as the list of possibly wrongly interpreted characters grows. In another attempt to increase the accuracy, some image processing was done. Attempts included changing the contrast, filtering colors, and converting to monochrome bitmap. This did not seem to have any significant, if any at all, effect on accuracy. This result was partly expected since Tesseract does image processing by itself using the Leptonica library [21].

Tesseract uses training data when doing its OCR scanning. This file contains information about the shapes of the letters used. This means that improved accuracy and speed can be achieved using a trained data file fine tuned to the ePassport’s machine-readable zone. In [22] , a specialized trained data file for MRZ can be found. Unfortunately this file caused crashes when performing the scan, likely due to a mismatch in versions the file was created for, and the version used in the application. This was encouraging to do some more research into creating test data for Tesseract, which led to a website that allows the upload of a TrueType-Font file and receive a trained data file for Tesseract [23]. This process was surprisingly easy and had a significant effect on both detection speed and accuracy.

To ensure that the information obtained from the OCR scan is correct, the machine-readable zone provides several check digits [24–26]. A method was implemented to check these digits to know when the machine-readable zone was interpreted correctly.

4 Connecting the dots

The goal of sprint two is a clickable demo of the app's UX[1] and a technical demo consisting of the connection between the blockchain and the app. During this sprint, testing was set-up for the various parts of the application. This chapter gives an overview of the work that was done and the problems that were encountered.

4.1. User experience design

As stated in Appendix F, the client offered a budget to use an external party to create a UX design for the application. At the end of the first sprint, a professional UX designer was hired at Milvum. To make the purpose of the first application clear to the designer, a wireframe was sketched on paper. During the second sprint, there were several meetings set up with this professional.

The main requirements for the UX design were that the user should be in control, it should be very clear what is happening and the app needs to feel trustworthy. The first two requirements can be accomplished by providing clear descriptive text and images indicating what is happening, or what will happen when the user performs an action. This can for example be seen in the bright green or red colors depending on whether redeeming the voting pass succeeded or failed. The latter requirement is a bit more abstract. To accomplish this the same colors as the Dutch government are used to give forth a sense of authority and security. Furthermore trust can simply be created by having a UX that makes the system looks finished and well thought about. This implies that other parts of the system have been developed with similar care. With these requirements in mind the UX designer started on his first prototype.

The first prototype was based on a sketch drawn with pencil and paper, to make clear which screens were needed, which emerged to a basic colorized workflow, visible in Figure B.1.

While discussing this design, there were some things that we thought were still sub-optimal which resulted in new insights. There was for example no way to select the current elections. Beside these minor changes, there were also some small detailed changes we came up with. E.g. the amount of ballot papers that should be handed was not very obvious, the process of scanning the MRZ isn't really a process which should be visible in a process bar. The design was also not fully compliant to the Android Material Design style guide as we wanted to see. The styleguide states that the app bar should be used for branding, navigation, search, and actions, not for notifications.

The feedback above resulted in a second iteration where these issues are improved. This result is visible in Figure B.2.

Besides design choices made by the designer, we made some of our own. One of these is about the status bar, we decided to make it transparent according to Material design guidelines. We added a top-padding to the action bar and enabled the transparent status bar. This way the color of the Action bar will shine trough the status bar giving it the same kind of color but darker. In the camera view the transparent status bar causes the camera feed to shine through he status bar, which is a nice effect in our opinion.

As part of the clickable demo, the design was implemented. During the implementation Android Material Design [27] was used as reference to get a uniform design which would feel familiar and logical for users.

[1]User experience

4.2. App permissions

The polling station app needs several permissions in order to perform its basic functions. These include:

- Camera permissions to scan the MRZ zone.
- NFC permissions to communicate with the document.
- Internet permissions to communicate with the blockchain.
- Storage permissions to store and read both the blockchain data and trained data for the OCR scanning library.

Internet and NFC permission are not considered dangerous permissions by Android, so these permissions are granted when installing the app and we can use them with no problem. The others, storage access and camera access, are considered dangerous permissions. This means that starting from API level 23 these permissions needs to be granted at runtime when the app requires them. For the camera permission, this occurs when the CameraActivity is opened after the user clicks the button to scan a document. The need for camera permissions in this case is quite clear to the user. For storage permissions the situation is different however, these permissions are needed right when the app is launched in order to store the downloaded blockchain data. The need for this permission is not very clear to the user and may be confusing when the app asks to write to the storage right after launch. For this reason an ErrorDialog was included in the app. When the app is denied one of the dangerous permissions, it will display a dialog explaining why the permission is needed.

4.3. Connecting to the blockchain

The polling station app needs to check the balance of votes spendable by the owner of the passport. In order to know this balance, something needs to look inside the blockchain and check unspent outputs. Clearly a connection to the blockchain is necessary. There are three ways of connecting to the blockchain. In this section, the advantages and disadvantages of these options will be taken into consideration.

JSON RPC

This is the easiest solution, because the app doesn't need to know anything about the blockchain. Downloading all the blocks will not be necessary and all the logic happens at the server. Only the signing of the transaction occurs in the app. Due to this, the system relies on one working webservice, which is a single point of failure.

The standard RPC service which is shipped with ePassportChain is also not designed to act in this way. For example, it relies on its own wallet which is attached to the node. So, before this RPC service can be used, ePassportChain has to be modified and some authentication rules have to implemented, or place some kind of proxy service between the app and the node.

Light wallet

In this case, the wallet functionality is embedded into the app. So the app is able to calculate the balances and is directly connected to the nodes in the network. The download of the entire blockchain can be a time and data consuming process. To fix this, light wallets rely on only the headers of every block with only the transactions related to the wallet included.

There are two problems with this approach: because it is desirable to have near instant verifications, the blockchain parameters are set to mine really small blocks in short intervals. Downloading only the headers will still be inefficient. The main Bitcoin network is set to mine a block every 10 minutes on average. With the parameters used in ePassportChain it is 10 seconds.

Experiments turned out that downloading headers with a size of 80 bytes runs at 1 kilobyte per second. The amount of headers produced in one day with a rate of 4 blocks per minute is $4 * 60 * 24 * 80 = 460800$ bytes, or 461 kilobytes. So downloading one entire day of headers will take around 7 minutes, which is not acceptable.

Another problem with this approach is that the headers are not enough to calculate the balance of voting tokens of every citizen. So, either the blockchain needs to be synchronized every time a passport is scanned, or the entire blockchain still needs to be downloaded.

Full node

Tackles all of the problems above, but it will be slow and will also be slower as the blockchain grows. This will also not be suitable for running on mobile devices.

Hybrid
To have the best of both worlds (light wallet and JSON RPC), the following approach might work. If the app doesn't have a local blockchain at all, but is connected to a node. Then it is still able to broadcast a transaction to the network. A rejection of a transaction is also broadcast back to the origin of this transaction.

Why not broadcast three transactions and see how many of them are rejected? This could be supported by a simple web service which returns the amount of voting tokens available in a wallet before the actual transaction happens.

Decision
The last option seems to be the most obvious solution. Unfortunately, during the implementation, it turned out that this is not possible due to the way transactions are built. A correct transactions needs a previous unspent output which needs to be queried from the blockchain. This resulted in the final decision: the full node. This is the easiest way to implement the solution as it includes all transactions in the chain, we can simply take an output and create a new transaction to sign with an ePassport. This will require the polling station app to synchronize with the network initially, which may take quite some time. After the synchronization is completed however, new blocks will be downloaded as they are mined so no more waiting is required. Also when querying for transaction outputs we can just inspect the local blockchain data, which will not require more internet activity unlike the light wallet implementation. Another downside may be that the device needs to calculate balances itself which may be an rather heavy operation on a large blockchain. However, it is expected that today's modern smartphones and future ones will be strong enough for this purpose. An analysis of this issue and the download times can be found in chapter 6.

4.4. Permission analysis

MultiChain has implemented a permission system, which enables permissions on address level. These permissions are thus also available in ePassportChain. The following permissions are currently available:[11]

- *connect* – to connect to other nodes and see the blockchain's contents.
- *send* – to send funds, i.e. sign transactions.
- *receive* – to receive funds, i.e. appear in the outputs of transactions.
- *issue* – to issue assets, i.e. sign transactions which create new native assets.
- *create* – to create streams, i.e. sign transactions which create new streams.
- *mine* – to mine blocks, i.e. to sign the metadata of coinbase transactions.
- *activate* – to change connect, send and receive permissions for other users, i.e. sign transactions which change those permissions.
- *admin* – to change all permissions for other users, including issue, mine, activate and admin.

As will be explained in section 4.5, anyone is able to connect to the network. This poses a minimal risk to the network since normal nodes (people) can only see what is happening in the blockchain. They cannot alter the blockchain in any way.

If an address has the *send* permission, it is allowed to send funds (i.e. a voting token) to another address. In order to redeem a voting pass, an address needs to send a transaction, so this permission is required for all voters. Still the parameter *anyone-can-send* is set to false. This is because the government needs to be able to retract a person's voting right, for example in the case that this person dies after the voting passes were sent, but before the election day.

Creating an asset or stream is considered as a transaction in MultiChain [28]. This means that rogue nodes can flood the network by, for example, creating many. assets. To prevent this only government nodes should have permissions to *issue* and *create*. However, the government nodes can be hacked and hackers can flood the network. This can be prevented by revoking these rights of these nodes after the vote tokens are distributed. A disadvantage of this solutions is that it is not possible to reuse the blockchain for a future election.

The mining right allows a node to generate a block. If there is monopoly of rogue nodes with mining permissions it is possible that fraud is committed. Without the mining right no blocks will be generated and no transactions will be verified. There need to be thus at least one mining node and this mining node should be owned by the government. Again, this mining node can be hacked, which is why it is desired to have several mining nodes owned by the government. Now the non-hacked nodes can reject a mined block from a rogue node.

With admin right it is possible to change permissions, either revoking or granting, of addresses. Revoking is useful when a person dies just before an election and this person has an account on the blockchain with a token. The government is now able to revoke the permissions of this person, so no other person can 'steal' the token by proxy voting.

A disadvantage of an admin account is that this account can be hacked, and can be used to tamper with the elections by granting himself mining rights for example. This can be prevented by revoking the permissions of the admin (the admin can do this himself). The problem with this solution is that revoking the permissions of other nodes is not possible any more, so a solution to revoke proxy votes of dead persons should be thought of.

4.5. Blockchain parameters

With ePassportChain it is possible to alter parameters of the chain. The parameters must be set before the initial run of a chain, after the initial run it is not possible to alter the parameters.

In this section the most important parameters, values of these parameters and a justification of these values will be discussed. Since there are more than 50 parameters, a complete list of the parameters, values and explanations can be found in Appendix C.

4.5.1. Permissions

The two parameters that will be discussed in this section are *anyone-can-connect* and *anyone-can-mine*, which are permission parameters. These parameters control if any node can connect to the blockchain and if any node can mine a block. Parameter *anyone-can-connect* is set to *true*, so any person can see what is going on in the blockchain and increase the trust of a person. The second parameter, *anyone-can-mine*, is set to false. This is done so only government nodes can mine a block, which ensures that a monopoly attack is not possible.

4.5.2. Blocks

A transaction is confirmed when it is contained in a block, so in order to verify an transaction swiftly, a block should also be generated swiftly. EPassportChain has two parameters which can influence the block time: *target-block-time* and *pow-minimum-bits*. The parameter *target-block-time* which is the target average time in seconds between two consecutive blocks. The other parameter, *pow-minimum-bits*, is the proof-of-work difficulty which must contain a value between one and 32. One is the most easy and 32 the most difficult.

If it is assumed that there are 13 million persons who cast their vote on a single day, where it is possible to cast a vote from 6am to 9pm, a calculation turns out that there are approximately 240 transactions per second ($13000000/15/60/60 \approx 240$). This is the average and since it is desired to handle more than the average, it is desired to be able to handle 480 transactions per second. Furthermore, a transaction is about 200 bytes and blocks are maximal one MB, there fit about 5000 transactions in a block. Now it is possible to calculate the target block time: $5000/480 \approx 10.4$. The *target-block-time* is set to 10 since only natural numbers are allowed.

To make sure that a miner is indeed able to mine a block in 10 seconds, the parameters *pow-minimum-bits* must be low enough. After some experimentation it is concluded that a proof-of-work difficulty of four is suited to mine blocks in ten seconds.

5 Full prototype

The last iteration of the development process was focused on creating a full prototype. This prototype shows the ability to redeem the voting token from the blockchain by signing transactions using travel document and a mobile phone. Furthermore this iteration was used to evaluate the functionality of the prototype by getting expert feedback.

5.1. EPassportChain compatibility with travel document

The world of cryptography is a tangle of different formats and systems. As stated in chapter 4, the entire blockchain depends on an elliptic curve which must be compatible with the travel document. Even with the right curve, there are other specifications that need to comply, which is also the case for the storage of the public key and signature.

A public key and a signature are basically stored as two very large numbers, which can be encoded in several ways. There are roughly three different format in use:

- String (hex encoded)
  - Compressed
  - Uncompressed
- DER (ASN.1 serialization of string)
- PEM (Base64 encoded DER)

Because of the compact size, the first hex encoded string method is widely used over blockchain technologies, which is also the case in ePassportChain. Public keys in this format can be compressed or uncompressed. Uncompressed keys are used to keep the transactions small. For the convenience of this research, only uncompressed keys are used.

However, the public key in the travel document group 15 is in DER format. This format is based on the ASN.1 serialization structure and contains other information about the key, such as the curve parameters. The last 80 bytes of this format represents the public key, these 80 bytes consists of two elliptic curve points of each 40 bytes. In the initial prototype of ePassportChain, the keys are encoded as an uncompressed hex encoded string. The initial prototype is thus not compatible with a travel document. Fortunately, this could easily be changed since CryptoPP is capable of dealing with elliptic curve points. EPassportChain now expects an 81 bytes long public key, the first byte is $0x04$ and the last 80 bytes contain the two elliptic curve points. The first byte informs ePassportChain that this is an uncompressed key. Although solely uncompressed keys are used currently, future implementations can benefit from this. Due to the fact that these are all bytewise operations to verify the signature of a public key in ePassportChain, it is really hard to support multiple elliptic curves. A different curve also results in a different key length. For this reason, this research is limited to only the last Dutch travel document standard, issues from March 9th 2014.

5.1.1. Building an ePassportChain transaction

As stated in chapter 3, the app uses the BitcoinJ library to keep track of the blockchain. This library is originally developed for the Bitcoin cryptocurrency, however MultiChain is a fork of Bitcoin and because of this is is quite easily adoptable in the project.

Because of the big modifications on the blockchain as shown in chapter 3, BitcoinJ has to be modified to make it work with ePassportChain. One of these modifications was altering the signing method and making it talk to the passport. In order to achieve this, the `LocalTransactionSigner` class was forked to `PassportTransactionSigner`, which also takes an extra argument which is the connection to the machine readable travel document. The rest of the transaction was built in the traditional way by adding the previous transaction and specifying new outputs. After the transaction was built and signed, it was broadcasted over the network (the one connected peer in the testing environment).

Unfortunately, this did not work as expected. The transaction got rejected immediately after broadcasting. Some investigations into this matter resulted in an error `could not connect inputs`. The transactions in ePassportChain are built according to the Bitcoin standard [1], which is not easy to understand, especially if there are modifications to the signature and the way the transactions are verified. After some debugging, it did not seem to be working using the transaction builder in BitcoinJ. However, to make sure that the this was not a flaw in the ePassportChain. Some cross checking is performed using a transaction built in ePassportChain CLI. This CLI is able to completely build a transaction, sign it and not broadcast it to the network (this was possible with the RPC call `createrawtransaction`).

In order to check if ePassportChain worked correctly, the transaction built with the CLI was encoded as a byte array and hardcoded in the testing environment which broadcasts it to the network. This worked as expected and the transaction became visible in the block explorer instantaneously. Based on these findings, it turned out that the ePassportChain implementation did work well and the fault was in the usage of the BitcoinJ library.

To gain complete understanding of the way a transaction is formed, a transaction was built using pencil and paper according to an online step by step guide [2]. This enabled us to keep control over the transaction at byte level. After a couple of little corrections the correct translation to the MultiChain style was made and it was accepted by the network. This made it possible to generate a transaction in the same style from code. To keep track of the code quality and respect the BitcoinJ structure, a decision was made to extend the standard `Transaction` class to a `PassportTransaction` class. This class is able to build an entire transaction on its own by providing an unspent transaction output and a passport connection. The transaction is built to send the entire amount of voting tokens back to the government wallet and sign the transaction using the provided passport connection. The broadcast of the transaction happens in the regular way using BitcoinJ.

5.2. System overview

This section gives an overview of the system in its form as full prototype. Using UML diagrams the In Figure B.3 screenshots of the final prototype are shown. This gives an idea of how volunteers of a polling station would experience the system.

In section B.3 an overview of the final looks of the Polling Station App can be found. Figure 5.1 shows a sequence diagram of the polling station application. It shows the normal flow through the activities on a voting day. The manual input activity is left out in this depiction. If manual input were used to enter info of the MRZ zone, then ManualInputActivity would replace CameraActivity and TesseractOCR.

5.3. Node organization

How should the government setup the nodes How many nodes are advised

5.4. Expert feedback

Five municipalities in The Netherlands have the intention to develop a voting app for holding local polls for various issues in their town, e.g. whether a roundabout should be created or not. They want to hold these polls under the same conditions as the nationwide elections in their current form. The vision for the long term is that the system for these local polls can also be used for nationwide elections. Since these municipalities are

[1] https://en.bitcoin.it/wiki/Transaction
[2] https://bitcoin.stackexchange.com/a/5241

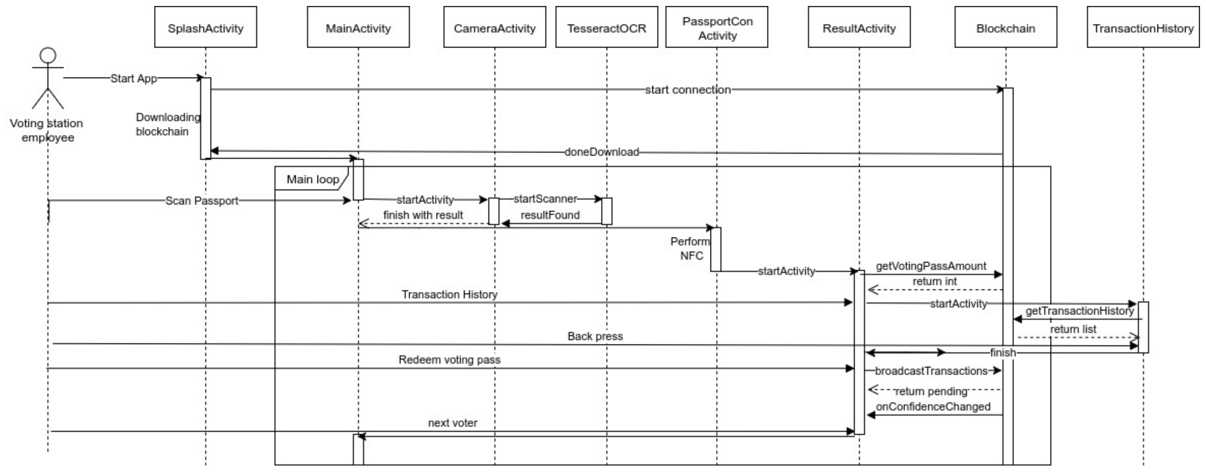


Figure 5.1: Sequence diagram of application

already in the process of developing a digital voting system, it is very interesting to get their opinion about this project.

We were brought into contact with the town of Emmen, located in the north east of The Netherlands, who are one of the five municipalities looking into digital voting. They were happy to receive us to talk about our proposed solution.

5.4.1. Why digital voting?

From the point of view of this project it is very interesting to know why a municipality wants to implement digital voting. They stated some very clear reasons:

- Easier to participate in elections for citizens
- Better accuracy for counting votes, current system is very fault-prone
- Faster counting of votes
- Much lower costs
- Easier organization, less logistical issues

These improvements are important for local polls. They need to be very easy to participate in, because people will probably give less priority to these polls in comparison to regular elections. Furthermore these polls will be held with a much higher frequency and going to the polling station every few weeks is just not viable.

The municipalities want to scale the application slowly to more people and more general use for elections. They are in contact with a few computer experts and will continue to keep experts involved in the process. With this combination of a slow build-up and the backing of experts there is time for the solutions to gain the trust of the general public. Our proposed solution fits in the idea of slowly building a digital voting system.

5.4.2. Demo of the proposed system

We explained the goals, scope, and setup of the project. Because not everyone was familiar with the technology used, a simplified explanation of blockchain was given. This was expanded to the concept of public/private key-pairs in combination with Dutch travel documents. After this theoretical presentation, a demo of the app was presented going through every step a polling station would also go through.

5.4.3. Feedback

The representatives of the municipality had a positive response towards the presented solution. They see the system as a nice first step towards a full digital voting procedure. Furthermore they were very interested in other applications of the passport connection from the passport to the blockchain, as this could solve some of the problems with digital identity. They also had some interesting points which should be addressed before the system is put to use in the real world. It should be possible to synchronize the blockchain with databases of the government to invalidate the digital voting pass of deceased people, currently this is done by keeping lists of uniquely identifying numbers of invalidated voting passes.

Currently the ballot papers and voting passes are destroyed 3 months after the election. This happens in order to have less discussions about the outcome of the elections a long time after they have taken place. Destroying an open system like a blockchain is not possible, since everyone has the ability to copy the blockchain, therefore the election outcome will be open for debate for a longer period of time.

In order to keep voting accessible for everyone, they want to keep the option for paper voting open. People who have serious objections to digital voting for whatever reason would still be able to vote on paper.

From a transparency point of view a digital solution would be a major improvement. Currently in The Netherlands it is possible to attend the counting of the votes. However, during the last election in Emmen, as stated by one of the representatives of the municipality, there was a very small amount of people who actually made use of that right. A digital solution would make this much easier.

5.4.4. Conclusion

It is great to get a confirmation that the goal of the project, creating a small step towards digital voting, is achieved by the proposed system. From the response of the municipality it becomes clear that compatibility with the current voting system is very important. They always want to keep the paper option open and even though one could argue that it is not needed to take into account everyone's preferences, this compatibility is essential for the slow adoption of a a full digital voting system. The proposed system allows for compatibility with the current paper voting system.

Finding a good solution for keeping the blockchain up to date with the governmental databases is something that will be a complex problem as this connection, going from centralized to decentralized, will be a weak point in the system. Close contact with system experts from the government will be necessary in order to find a good solution for this connection

Not being able to throw away the blockchain will probably not be a major issue. With the increased accuracy of counting the amount of voting passes there will be less discussion about the election outcome. Therefore it is no problem if the blockchain is available a long time after election, it even increases transparency which has a positive effect on trust in the voting system.

6 Performance analysis and evaluation

MultiChain is able to process 200 to 800 transactions per second [29]. This depends on what kind of hardware a node is running. Since ePassportChain uses the brainpoolP320r1 elliptic curve instead of the secp256k1 elliptic curve, the performance of ePassportChain might be affected. In order to understand the impact of the changes in comparison with MultiChain, several performance tests were executed and evaluated.

In particular, four performance tests have been executed which simulates the entire process; ranging from the creation of an election to voters claiming their right to vote. Each test will be discussed in a separate section and has a fixed layout. First, an elaboration of the setup is given, which discusses how a test is performed. After this, the results are discussed and evaluated. All tests were executed on a single machine which is a MSI GP62 2QE Leopard Pro. This machine has an Intel® Core™ i7 5950HQ, 8GB of RAM and SSD storage.

6.1. Verifying transaction

This performance test will try to measure the difference in time between verifying a single transaction with MultiChain and ePassportChain. To verify a transaction, a hash of the transaction, signature and a public key must be provided. Before trying to verify a signature using a public key, the public key itself must be checked for validity. In this test, the time to verify a public key and a signature is measured, because both are tested for correctness every time a transaction has to be verified.

6.1.1. Setup

In this test two new chains were created, one for ePassportChain and one for MultiChain. 1000 public keys of both chains were created and stored in a csv file. For each chain, a python script has been used to send 1000 transactions to the 1000 public keys. This script communicates with the a node via RPC. All transactions were sent to a single node, which verifies all transactions. This node would then return the elapsed time, in milliseconds, it took to verify a single transaction.

6.1.2. Results

Two test runs have been completed and the results are shown in Table 6.1. This table clearly shows that MultiChain performs significantly better than ePassportChain.

	MultiChain	**ePassportChain**
Run 1	0.0655 ms	17.1 ms
Run 2	0.0721 ms	17.3 ms
Average	0.0688 ms	17.2 ms

Table 6.1: Elapsed time of verifying a transaction

The main difference comes from the fact that secp256k1 is 30% faster than most elliptic curves [30]. In contrary with other elliptic curves, secp256k1 signatures can be efficiently computed since secp256k1 generates signatures in a non-random way. Next to this, ePassportChain uses the CryptoPP library which is not optimized for the brainpoolP320r1 elliptic curve. Furthermore, MultiChain has an optimized implementation of the secp256k1 elliptic curve from which it benefits significantly. The last difference comes from the fact that ePassportChain must verify a signature four times instead of one, as explained in subsection 3.1.1.

In order to calculate the impact of verifying only one signature in ePassportChain, another test has been executed. This test measures the time it took to verify one part of a hash, and thus verifies one signature. Using the same setup as discussed in the previous section, 1000 transactions were sent to a single node and the results were gathered. This test showed that verifying one fourth of a hash on average took 2.85 milliseconds. From this data it is possible to calculate the hash verify time when it is possible to sign the whole 32-byte hash in one go:

$$17.2 - 2.85 * 3 = 8.65 \text{ ms}$$

This means that in the future, when a travel document is able to sign more than 32 bytes, performance can be increased. Verifying a signature can be almost twice as fast, if CryptoPP is used.

6.2. Creating elections

Before a voter can claim his voting right, the voter must have at least one voting token on ePassportChain. The voter receives its token from the government, since the government knows who is eligible to vote. This means that the government first has to distributes TOKENS to all individuals who are eligible to vote. As stated before, there are about 13 million persons eligible to vote which means that the government has to distribute about 13 million TOKENS. In this section, the creation of elections is simulated and the performance of ePassportChain is analyzed. In addition, the size of of the chain and the time it takes to create an election are measured in this test.

Setup

In order to create an election, a python script has been created. This script first creates an asset on the chain which represents an election. Then it loads public keys from a csv file and converts these public keys to ePassportChain addresses. Subsequently, every address is granted the appropriate permissions and the script sends one voting token to each address. The python script sends the transactions to a single node which processes all the transactions. All of these steps are done via RPC, specifically the following calls are used: `issue`, `grant` and `sendasset`.

For this test 400 assets have been created and for each asset a csv file containing 1000 public keys has been used, thus creating 1000 addresses where voting token can be send to. This means that in total 400000 transactions are generated and processed in this test. For each asset the elapsed time to generate and process the 1000 transactions is measured. Furthermore, the size of the chain is measured at 3 different moments, after 100000, 200000, 400000 transactions.

Results

In Figure 6.1 visualizes the elapsed time of creating 400 assets were each 1000 transactions were handled. The drop between 250000 and 275000 transactions can be justified by the fact that testing machine was only used for processing transactions in this period of time.

From this figure it is clear that the time it takes to process transactions stays constant when the chain grows. The average processing time of 1000 transaction was determined to 37.3 seconds. With this information it is possible to calculate how long it should take to create an election for 13 million people:

$$\frac{13000000}{1000} * 37.3 = 484900 \text{ seconds} = 5.61 \text{ days}$$

This means that a government must at least create an election six days before the actual elections if the government runs similar hardware. Better performance can be expected when an election is created on superior hardware.

In Table 6.2 the size of the chain after 100000. 200000, 300000 and 400000 transactions can be found. Using this data, it is possible to calculate how fast the chain grows in size, which is determined to be around 78.5 MB per 100000 transactions. From this, it is possible to calculate the chain size after 13 million transactions:

$$\frac{13000000}{100000} * 78.5 = 10,2 \text{ GB}$$

. Ten gigabyte is quite big but can be downloaded by a mobile device with via WiFi connection on a single day. Furthermore, the mobile device which runs the polling station app, needs to have at least 21.4 GB (twice as many since 13 million voters also create transactions) of storage to be functional.

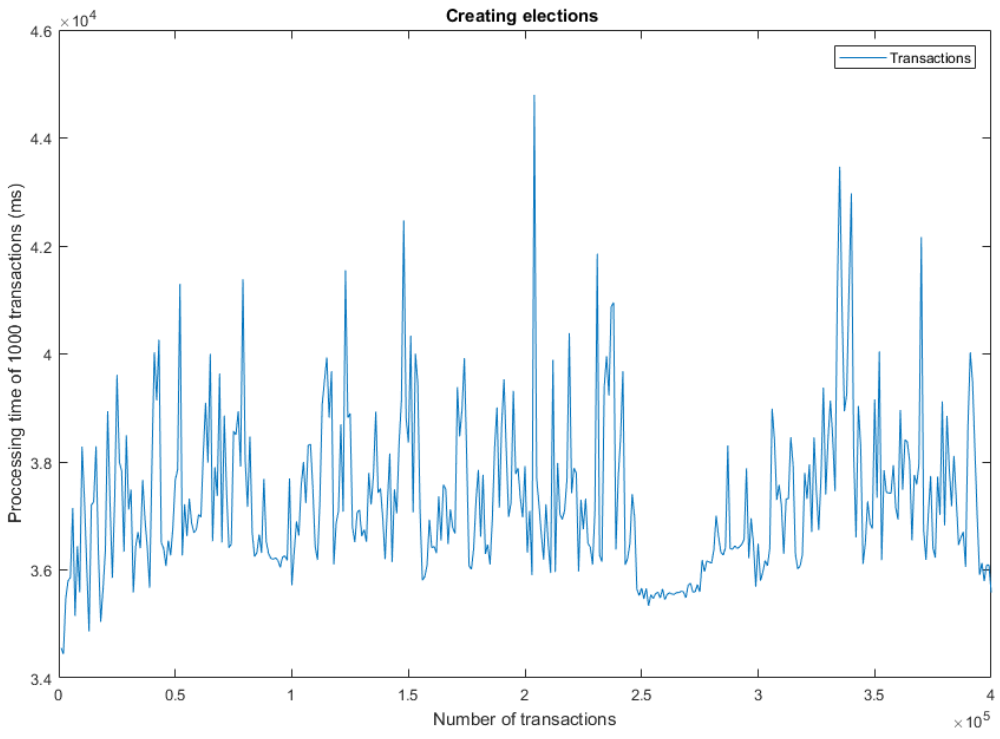


Figure 6.1: Simulation run of the creation of an election on ePassportChain

Number of transactions	Size of blocks (MB)
100000	95.0
200000	173
300000	252
400000	331

Table 6.2: Impact of transactions on the size of ePassportChain

6.3. Simulating the voting process

This test simulates people claiming their voting right at the polling station. Specifically, it measures the time it takes to verify multiple transaction by a node. In a real world scenario voters will claim their right from almost 9000 polling stations [31] and thus 8000 transactions could be send concurrently. From the results of these tests, it should be clear whether or not it is feasible to create one ePassportChain for 13 million voters.

Setup

This test is different than previous test as described in section 6.2. The test from section 6.2 builds a transaction on the node itself and thus signs and verifies the transaction on the node. In contrary with the test described in this section, a node only verifies a transaction. The test creates 1000 new addresses and send each one a voting token. Subsequently, it creates 1000 transactions (one for each of the 1000 addresses), signs these transactions and stores the signed transactions. Finally, the signed transactions are loaded and send to the node which solely verifies a transaction and measures the elapsed time it takes to verify all 1000 transactions. Similarly, in a real world scenario a transaction is build on a mobile device and send to a node which in turn verifies the transaction.

To ensure the data from a test run is not exceptional, the test was run 100 times.

Results

In Figure 6.2, a boxplot of the results is shown. The mean of 100 tests runs is 23.5 seconds.

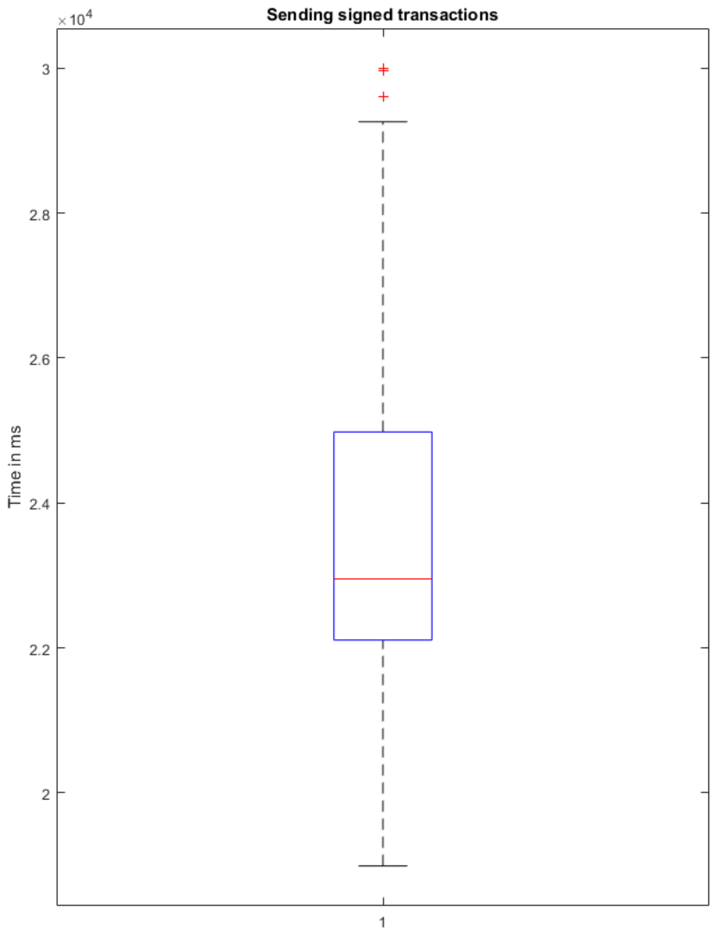


Figure 6.2: Boxplot of a simulation run of sending transactions on ePassportChain

The following calculation shows how long it should take to verify 13 million transactions:

$$\frac{13000000}{1000} * 23.5 = 305500 \text{ seconds} = 84.9 \text{ hours}$$

Obviously, 84.9 hours is too much for an election. Besides this, a voters voting right can only be redeemed when a transaction is contained in a block. Therefore, when there are too many transactions the network can process, there will be many unconfirmed transactions. This will result in a greater waiting time; and thus annoyance of a voter.

A possible solution to this problem could be to create separate ePassportChains for different regions. This way the load can be divided and the waiting time of a voter is reduced. The size of a region should depend on the number of transactions ePassportChain can process in 10 seconds (the target block time) and the number of polling stations. These numbers should roughly be equal so the number of unconfirmed transactions does not grow when a new block is mined. The maximum number of transactions that can be processed in 10 seconds can be calculated as follows:

$$\frac{1000}{23.5} * 10 = 425 \text{ transactions}/10 \text{ seconds}$$

. This means that approximately 425 transactions can be processed in 10 seconds. It is recommend that a single ePassportChain is used by around 425 polling stations. However, it is possible to have, for example, twice as many polling stations, but this will double the waiting time of voters.

6.4. App performance

When the polling station app is initializing, it is downloading the chain (or new blocks). In this test the time it takes to initialize the app is measured. It will do this by measuring the time it takes to initialize the app when ePassportChain contains 0, 1000, 2000, ..., 8000 transactions. From this data it is possible to calculate how long it should take to initialize the app after an election has been created.

Setup

The app is run on a OnePlus One device, which connects to a single node and downloads the chain from this node. Initially, a new ePassportChain is created containing zero transactions. After the chain is created the following steps are taken:

1. Clear the data and cache of the app
2. Send 1000 transactions to ePassportChain
3. Start the app and measure the time it takes to initialize the app
4. Repeat until there are 8000 transactions in ePassportChain

Result

The result of this test can be found in Table 6.3 and a graph of this data is shown in Figure 6.3.

Number of transactions	**Time (s)**
0	5.43
1000	36.1
2000	87.6
3000	158
4000	277
5000	399
6000	590
7000	796
8000	1063
9000	1407
10000	1788

Table 6.3: Elapsed time for the app to initialize

Figure 6.3 shows that the time it takes to initialize the app is neither linear or exponential. Even if we assume that the elapsed time grows linear with 350 seconds per 1000 transactions and we create separate chains as discussed in section 6.3, it clearly performs poor. The time it would take to initialize the app when the chain contains 1 million transactions can be calculated as follows:

$$350 * 1000 \approx 4 \text{ days}$$

This is unacceptable for major elections such as the parliamentary elections.

6.5. Security level

The application is built upon two key elements: the blockchain and the machine readable travel document. These key elements are the most important factors of the security aspect of this project. The following sections will cover the possible flaws in these parts of the implementation.

6.5.1. Blockchain

The ePassportChain is set up in a decentralized way, which means that everyone is able to take part in the network. In order to prevent a 51% attack on the network there are rules to which every client has to comply. One of these rules is the authorization to mine new blocks, which is limited to the government node. If anyone tries to alter the parameters and set up its own ePassportChain, it will not match and the polling station therefore

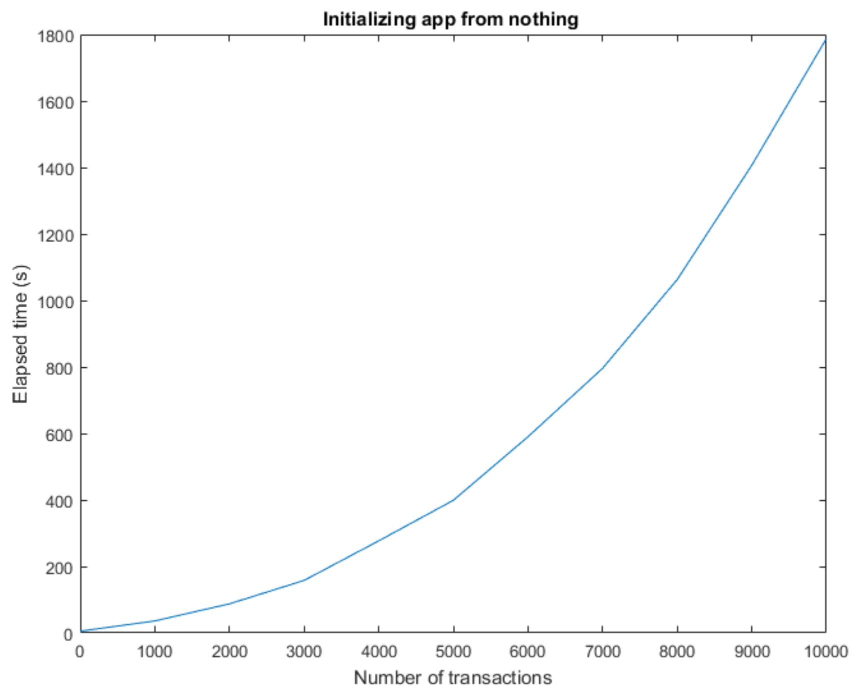


Figure 6.3: A graph of the time it takes to initialize the app when there are between 0 till 10.000 transactions in ePassportChain

will not be able to connect to the new node. The genesis block contains these parameters and is part of the blockchain.

Another attack would consist of intercepting the private key from the government. If this happens the attacker would be able to provide its own voting tokens and mine blocks by itself. Such an attack would be visible by anyone with access to the blockchain, especially the government itself will see unauthorized transactions happen. Even though the attack will be detected, preventing it is preferable. In order to prevent the leaking of the private key, the government should conside a hardware wallet [1]. This hardware wallet ensures that it is not possible to read the private key from the device (like the epassport). However, it will still be possible to sign transactions using this hardware wallet.

6.5.2. ECDSA passport

To visualize how hard it is to break a security, the concept of universal security was introduced by Lenstra [32]. In this research the security level of an application is expressed in the amount of energy needed to break the encryption. The Elliptic Curve used by Dutch travel documents has a key length of 320 bit. According to Lenstra's research, an Elliptic Curve key of length 228 bit is comparable with an RSA key with bit length 2380. This key has strength "global security" which means that the breaking of the key requires the amount of energy needed to boil all water on earth.

The implemented solution, however, does use ECB for signing the hash of a transaction. ECB means that different blocks are encrypted or signed separately. This may result in some vulnerabilities. ECB chaining has the following limitations [33]:

- If the blocks are the same, the ciphertext is also the same.
- If the blocks are independent, it becomes possible to replace blocks in the ciphertext
- If one bit is inserted or lost in the ciphertext, the decryption of the entire ciphertext will go wrong

The first limitation is not a problem with Elliptic Curves due to the way the signatures are generated. The signatures are generated non-deterministic, due to the addition of a random number. Signing the same data twice with the same key will result in two different valid signatures. Secondly, replacing independent blocks

[1] https://en.bitcoin.it/wiki/Hardware_wallet

is not really an issue in this implementation, because the only data that is signed is a SHA256 hash. The four blocks in this hash are not independent and cannot be used individually. At last, the insertion of a bit - which may occur due to hardware failure - will only result in a rejected transaction. It will not compromise the security.

This analysis is performed without any background knowledge of encryption and should be verified by an cryptographic expert before it is implemented in production.

7 Quality assurance

Good quality code is essential for a successful software project. In accordance with the Project Plan (Appendix F) the quality of the code is maintained by creating tests, using continuous integration and by the expert feedback of the Software Improvement Group (SIG). This chapter elaborates on these specific components for maintaining quality code.

7.1. Software Improvement Group

There is no exact measure for good code. It is especially hard to define exact measures since software can have very different goals and therefore a totally different structure. However, the software engineering industry strives towards reaching agreements on code quality. This resulted in ISO 25010, which defines a quality model for code in more general terms. The existing agreements on good quality code are mainly focused on maintainability: the ability to change code without much effort and generally being able to easily analyze code.

The best way to get an idea of the quality of code is to compare it to similar software. When software is comparable to most of the software that is released, it is certain that the software delivered has the same quality as the industry standard. When there is any difference, further analysis should point out whether or not that is positive for this particular piece of software.

With this idea in mind the Software Improvement Group (SIG) was founded. They provide a benchmarking service for code, comparing it to the data they have of their many costumers. SIG provides this service for all the TU Delft Computer Science Bachelor projects. For these project there are two benchmark points, one in week 6 of the project and one in week 10. The entire code base is uploaded to SIG, after which they provide feedback in the form of stars and an expert review. The stars (1 to 5) indicate the quality of the code in comparison to other code bases.

7.1.1. First code submission

The first submission included the code of the app (at that time not yet including the connection with the blockchain) and some scripts to easily issue digital voting passes. SIG has the policy that when third party code is adopted, the new owner is fully responsible for the code. We make use of the Multichain library which is about 230.000 lines of which we edited about 400 lines. Because it is unrealistic to check and fix multiple man years of code while we changed so little, we decided against including these libraries in the SIG submission. Such a large library would also defeat the purpose of the SIG upload, namely checking if we write good quality code.

Feedback

The feedback on the submission was very positive. The code received four stars on the maintainability scale, this means that the code is above average maintainable. In order to get five stars the unit size should be looked at, which was above average large. Especially the class relating to the camera preview for OCR had very large methods. As a positive aspect the amount of test code was mentioned.

With this feedback in mind the code was revisited to reduce the unit size and to refactor the code in order to better distribute responsibilities. Larger methods were split up into multiple methods having a more distinct responsibility, reducing the unit size. The camera related code was split up into multiple classes creating a better overview of where certain functionality resides in the code and thus increasing maintainability. Furthermore we continued creating unit tests where possible and integration tests for other parts.

7.1.2. Second code submission

In the second submission the same repositories as with the first submission were submitted, now with the polling station app in its full prototype form. Again, large library files were excluded. Because the same repositories were submitted, the progress of the code quality can be analyzed easily.

Feedback

At the time of writing the feedback on the second submission was not yet received.

7.2. Testing

When editing parts of a software system it is almost inevitable that some functionality breaks and stops working as intended. It is very important to notice these failures early on, before the product is released to the public or before more code is created using failing building blocks. To help in noticing these failures and to ensure parts of the code are working as intended, tests should be created. These tests are able to run a small part of the entire code base in order to test their specific functionality. Combining tests with a building service like Travis CI[1] creates an automated system which warns you when an alteration to the code breaks anything, this is called continuous integration.

We have made use of continuous integration for the entire developing process of the polling station app. Although this is generally considered good practice because issues are detected early on, not many issues were fixed with the help of Travis. Most of the time errors raised by Travis were caused by compatibility issues between Android and Travis or by setup file issues. This raises the question whether or not it was worth it to use Travis or continuous integration in general for this project.

Some functionality of the product is so complex and has dependencies in such a way that it can't be tested with regular unit tests and therefore is harder to test with continuous integration. Because of many issues with Travis and integration tests, this functionality was not included the continuous integration setup. How this functionality was tested is explained in detail in the sections that follow.

7.2.1. Passport connection

The passport connection related methods all work with the Passportservice class from JMRTD. This Passportservice handles all requests and responses to and from the passport and makes use of an Inputstream. Because in unit tests an passport (hardware) can't be used, this Passportservice is mocked as well as the stream of data coming from the chip.

The inputstream is mocked with data that represents a ECDSA public key, which should get handled similarly to data from an actual passport. However, this raises an exception in the method that reads the public key from the data. Even when actual data from a passport is copied and used as inputstream, it still raises an exception.

Because a lot of time was spent on trying to get these tests to work without any result, it was decided to not test these methods by using unit tests. Instead AndroidTests or a testing plan could be set up to manually test the functionality of the passport connection before each release. Even though this means Travis CI can't be used for continuous integration tests, this proposed solution is a way to ensure no functionality is broken by new releases.

AndroidTests or instrumented/integration tests are used to test software on dedicated hardware. This project has a problem in that several user actions are required for testing the full functionality (e.g. scanning the OCR and holding the passport to the phone). This makes it very hard to test for specific cases. Only the case of a successful passport connection can be tested, but this is the same as testing the functionality of the app. It was decided that creating separate tests for this is not worth the time. Testing for how the app handles the error cases (e.g. passport is held to the phone too short) is possible by using regular unit tests. Since the tests will handle the null cases, there is no need to mock any data streams, which makes testing easier. Testing for the handling of the NFC tag discovery was not successful, because Mocking NFC tag intents is not possible, methods to do so are not available in newer Android versions.

[1]https://travis-ci.org/

For each release to master, a testing plan should be performed in order to ensure non-tested functionality of the application is still working. The test plan for the passport connection can be found in section D.1. Using a test plan instead of unit tests or integration tests has serious limitations. The amount of test cases is very limited and it is much harder to test for rare bugs. Furthermore it is hard to maintain a consistent test environment, which would make it harder to debug. Although this setup is far from ideal, it is sufficient to ensure a working prototype for releases.

7.2.2. Optical Character Recognition (OCR)

Because Tesseract uses a number of dependencies that cannot be mocked, AndroidTests were used instead of regular tests. AndroidTests allow for executing tests in an emulated environment or on actual hardware.

Using AndroidTest and images of traveling documents it was possible to verify the accuracy of the OCR scanning. During the use of the application the OCR scanner scans a series of pictures until it recognizes a correct MRZ (verified by checksums). Therefore there is no need for 100% accuracy on each picture. To account for this a threshold was set for accuracy in the tests. This accuracy was calculated using the Levenshtein distance. The resulting MRZ code from the OCR scanning of the test images should at least have a reasonable accuracy, like 95%. By setting the accuracy threshold to just below the lowest performing test, any drop in performance of the OCR scanner can be detected by continuous integration, since test will start failing.

These tests are also essential in order to test for improvements of the OCR. Using the accuracy improvements to the OCR scanner can easily be detected. After creating these tests several trained data files were tested to see if any caused an improvement in scanning the MRZ. Eventually a trained data file was created based on the OCR-B TTF file. This resulted in a 5 percent increase in accuracy. In the real world, however, it resulted in much faster recognition of the MRZ. On passports where reading the MRZ used to be impossible, now the scanner recognized the MRZ immediately after the camera had a good focus. This improvement is very important for the ease-of-use requirement of the system.

7.2.3. ePassportChain

Testing ePassportChain seemed to be very tough since MultiChain itself does not have any public test code [34] and thus as a consequence a custom Makefile, which compiles a test, had to be created. Several attempts have been made to create such a Makefile, but the build always resulted in a few undefined references, for example: undefined reference to type *mc_gState* in *chainparams/globals.h* and *utils/utilwrapper.cpp*. To overcome these problems, the headers containing the declarations of these types were included where needed. This allowed to build a test suite for ePassportChain, but unfortunately including these headers broke the build of the daemon and CLI of ePassportChain. Most errors were in the form of: multiple definition of variable X, where X is a variable from the extra includes headers.

Fortunately, this error can be solved by only including the headers, which contain the declaration of *mc_gState*, when the environment variable UNIT_TEST_MULTICHAIN is set. This way it is possible to build the test suite and the ePassportChain daemon and CLI.

Since only a minor part of the MultiChain code was altered. The implemented test suite only tests whether loading, storing, signing and verifying with keys works as expected. To ensure that changes to ePassportChain don't break functionality, a test plan has been created, which can be found in section D.2. This test plan must be completed after each change to ensure everything still works as expected.

8 Societal Impact

Voting is a very important part of democracy. The core of democracy, having influence as a citizen, is compromised when anything goes wrong during the voting process. Because of this, it can be expected that adoption of the proposed system in this thesis or systems alike will cause society-wide debates and therefore have a serious impact on society even before they are implemented.

The fact that digital voting is often met with skepticism, is not strange. Fears for digital solutions include large scale fraud, violation of secret ballot, and meddling in election by other governments, as became clear when digital voting was discussed in the Dutch House of representatives on May 17th 2016. [35] The argument of external governments meddling in elections has become more prominent since accusations of Russian interference in the 2016 US presidential elections.

8.1. Political response

Changing the voting process is politically sensitive. Even a relatively simple alteration like changing the size and layout of the ballot paper is met with resistance. [36] Especially proposals for digital alternatives are met with a lot of resistance. In the past years every proposal for experimentation with digital voting was declined. Because there was so much negative feedback on the previous digital voting system, any new system will be looked at with sceptisim. Because voting is such an integral part of the democratic system, any failure in the system degrades the democratic constitutional state. Anyone responsible for the failure will be facing a lot of criticism. A secretary who is responsible for the implementation of the failing system will possibly have to resign. For these reasons it is not strange that politics is hesitant to change anything in the voting system while no big problems have come to light in the current system.

People place trust in the current paper system because everything can be verified and it is hard to commit fraud on a large scale. Recently however, it was uncovered that with the last election large numbers of votes were not counted, in total around 14.000 [37]. It can be expected that this will spark a debate in parliament whether or not the current system is safe enough. This would also be the right moment to bring up solutions like the one proposed in this thesis.

8.2. Required legislative changes

The Dutch voting process is thoroughly described in the law (Kieswet). Any changes to the voting process therefore require changes in law. By adopting an experiment law for voting, it would be possible to experiment with other forms of voting processes without having to change the law describing the voting process. Such an ‘experiment law‘ has been used to create the possibility for experiments with voting passes for Dutch citizens abroad [38] in the past. A proposed experiment law for allowing tests for the use of electronics during the elections was turned down by parliament in 2016 with about two thirds of parliament against. [39] It took about 3 months from the first proposal of the law till the vote in parliament.

It can be expected that when there is no major political against the digitalisation of the voting pass an experiment law could be passed within a few months. Changing the actual voting law (Kieswet) will probably take a lot longer, up to multiple years. This can be derived from the reasoning to propose the in 2016 turned down experiment law. It argued that the experiment law was needed to able to start the use of electronic voting systems without having to wait for a law-change process that could last multiple years.

8.3. Trust in the system

It is obvious that the system must be secure to prevent anyone from influencing the election outcome and that people should trust the system. But trust is not directly correlated with security of the system. It can be seen as a combination of safety (does the system perform as it should under normal circumstances), security (is the system tamper proof) and how this safety and security is perceived. A system might be perceived as secure and therefore be trusted, even though it is not secure at all. The other way around is just as undesirable, because when people don't trust the system they might not want to vote or won't respect the election outcome. Trust in the system, therefore, is a key aspect of developing a working digital voting solution.

In 2007 De Jong et al [40]. researched the difference of trust in voting procedures. They concluded that people had a little bit more trust in voting machines than a paper procedure. People had more confidence in the correct counting of the votes with machines. A paper procedure, however, was considered more anonymous. Since that time a lot has changed in the perception of digital solutions. Nonetheless, the fact that 90% of Dutch municipalities would like more research on digital voting solutions, shows that the public still has confidence in these solutions.[41] These municipalities wouldn't show interest in these digital solutions if they know that their citizens don't trust them.

The trust of the general public in a digital solution will probably be influenced in a major way by the opinion of experts. Therefore developers of any digital voting solution should aim to convince these experts of the safety and viability of the system.

8.4. Changes for voters

In the most recent parliamentary elections in The Netherlands 10.563.456 people cast their vote, this is a turn-out of 81.9% [42]. This means that many people come in contact with the voting process. The system should be accessible for everyone and it should be known what the effects of a new system are on the voters.

Changes in a system or processes often cause problems as people need to adapt. It can be expected that in such a large group of people like the eligible voters in The Netherlands, there will be people who are not aware of the system change. Therefore this thesis proposes a transition phase where people can opt-in for using the digital voting pass. After a few elections, when the system will be optimized and proven to be working as intended, people will have more trust in the system and it will be easier to force people to start using the new system.

8.4.1. Positive impact

The proposed system is easier to use for voters, since they only need to remember to bring their traveling document, which most people have on them most of the time. Because the system is easier, it could be expected people will be more inclined to vote, even though it is hard to give a good estimate on this. An easier form of voting in Estonia, where people can vote via Internet, only slightly increased the voter turn-out [43]. Research by Allers and Kooreman showed no statistical increase in voter turn-out in Dutch elections comparing paper voting or voting machines in the 2003 and 2006 Dutch elections [44]. Because cultures and voting solutions differ so much it is hard to distill anything useful from previous research for our specific solution. Research and experiments should make clear whether or not a positive effect on voter turn-out can also be expected in The Netherlands.

In a day and age where a large part of processes are already digitalized, the voting system runs behind. The reputation of voting could be improved by having a digital system associated with it, making it less old-fashioned.

An open-source voting system involving Blockchain maximizes transparency of the voting process. With the right infrastructure in place (which can be created by anyone) the voting process can become extremely transparent for any citizen with basic knowledge of technology. Increased transparency allows people to fully understand what happens with votes, which increases the trust in the voting process and democracy as a whole.

8.4.2. Negative impact

At first it might be hard for people to understand why our proposed system is safe. Also the relationship between a travel document, a phone and a voting pass might be hard to understand. Very clear explanations of the system are essential in order to take away any misunderstandings about the system.

Related to this there are people who fundamentally distrust digital systems. Often this has to do with incomprehension of the technology. Effort should be put into persuading these people the system is safe.

9 Conclusion

This paper presents a fully working prototype that can replace the existing system of voting passes in the Netherlands which removes the necessity of sending paper voting passes to all Dutch citizens that are eligible to vote.

Using multiple open source libraries and frameworks we were able to integrate the ePassport standard with blockchain technology by signing blockchain transactions using the chip present in travel documents. This project is the first in the world to show this possibility. The combination of ePassport and blockchain guarantees that only with a valid traveling document a voter can redeem his vote. The combination of fully open-source code and the natural transparency of blockchain technology creates a fully transparent system, which is a necessity in order to build trust for the system. Furthermore, the system simplifies the redeeming of suffrage and increases accuracy of voter turn-out, which improves the detection of fraud within elections. By developing an Android app, we presented how the system could be used in polling stations.

By conducting literature review, we showed that the key aspects of the system are very secure, better analysis by security experts is still required for confirmation. While the system performs very well in a small testing environment, it has some scalability issues. These issues can largely addressed by splitting the system up into parts and further optimization of the blockchain.

After performance issues are addressed, some minor improvements as stated in section 9.1 are needed after which it can be integrated in the current Dutch voting system. The system could therefore be used as a first step towards a fully digital voting system.

The use of the ePassport standard to authenticate people could be applied to many other problems that need to deal with digital identity.

9.1. Recommendations and improvements

Our solution to digitalizing the voting pass of the Dutch election system is not perfect and can be improved in multiple ways. This includes improvements for both security and integration in the current Dutch voting system. This section explains ways in which our solution could be improved in order to support all features of the current system and provide enhanced security and confidence.

9.1.1. Proxy voting

Proxy voting, the process of allowing someone to legally cast your vote for you, is not supported by our current implementation of the digital voting pass. We have, however thought about how this could be implemented. It is important to note though that in a working, complete digital voting system proxy voting becomes unnecessary. If a complete digital system is realized where any registered voter can vote digitally and remotely, the process of voting itself is so fast and simple that anyone can do it at pretty much any time.

Because in our digital solution to the voting pass each voter still needs to go to a voting booth in order to cast their vote. Proxy voting can still be desirable in this situation, if a person is not able to go to the voting booth for whatever reason.

An identity document is needed at the polling station in order to claim a voting ballot. Since it is illegal to use someone else's identity document **??**, it is impossible to cast a vote for another person by bringing their document to the polling station. Instead, a system needs to be implemented to allow voters that have received a digital voting pass to spend some other persons digital voting token token. The simplest implementation of this would be to allow voters to transfer tokens to each other, and so allow the documents of the receivers to sign transactions spending those tokens and get an additional voting ballot. This approach is also discussed in the research report. Another proposal is to change the wallet of these votes to a multisignature one, allowing the proxy voters to spend those tokens as well.

In the current dutch voting law, one person may not issue more than three votes in total. So, in order to conform to the law, this would need to be enforced within the blockchain so that any transaction that attempts to acquire more than three votes for an address is rejected.

We imagine granting a vote to someone can happen easily and quickly with an additional app. This app would need to read both the documents of the granter and granted. It would read the public key off the document of the granted person, and then using the document of the granter, a transaction can be created and signed that sends the voting token token.

9.1.2. Multisignature wallets

Multichain has full multisignature support [45]. This can be exploited in our app in order to add two additional features.

Firstly, multisignature wallets can allow the government to retract anyone's voting rights. If the government key is given the authority to sign transactions of all wallets, it can simply create a transaction to take away someone's voting token token and so his or her right to vote. This can be necessary when a person dies just before election day for example.

A second application for multisignature wallets is about making the system less complicated for voters. In the current implementation a ballot paper can only be claimed using the same document that the government sent the token to. In reality some people have multiple different documents, and they won't care which one they use to vote. Instead of making people remember which of their documents to bring, their token could be sent to a multisignature wallet that allows both documents of said person to sign a transaction to spend the token.

9.1.3. Driver's licence support

Dutch drivers licences also have the same chip embedded as ePassports starting end November 2014 [46]. This means that the driver's licences starting from this date can be used in the ePassportChain just like passports and ID cards. Since no driver's license was available during development, this functionality is not included in the polling station app. But it should be quite easy to implement this functionality.

9.1.4. Possible safety improvements

Aside from functional improvements, some security improvements can be made as well. These improvements can ensure that a person showing up at a polling station, is actually the legal holder of the document. There are both biometric and regular authentication methods possible for this purpose.

Facial recognition

Something that could theoretically be implemented right away is facial recognition. Since the picture on an identity document is downloadable by anyone having access to it, one could pull this picture and run facial recognition software on it, comparing it to the voter standing in front of a camera at the polling station.

Fingerprint authentication

Another more reliable method of ensuring document ownership could be fingerprint authentication. This however, would be a lot harder to accomplish and met with a lot more resistance. First of all because fingerprint information is much more privacy sensitive information. Storing this info anywhere else than in memory for the authentication would be a no-go. Additionally, it is currently impossible to extract the fingerprint information out of the passport for a third party like ourselves. In order to realize this the government would need to grant special privileges and an access key so this information can be accessed.

Brain wallet

A third option for additional authentication could be the combination of a brain wallet with the travel document. A brain wallet uses a list of words or password as a seed in order to generate a private key. This can be used as an additional layer of security by making all wallets 2 of 2 multisignature, meaning that both private key signatures are required for the transaction to be valid. One of these signatures would be the ePassport generated one, and the other would be generated by the device given the brain wallet pass phrase. This way both the travel document and the pass phrase would need to be present on order to redeem suffrage.

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A Requirements

A.1. Blockchain implementation

A.1.1. Must Have

1. The blockchain must verify transactions with the ECDSA curve BrainpoolP320r1.
2. A voter must be able to claim his vote right only one time and no more, either with a digital voting pass or physical voting pass.
3. The government must be in control of the blockchain.
   (a) The government must be able to transfer votes to wallets of eligible persons
   (b) The government must be able to control which nodes are able mine
4. The blockchain must accept a transaction when the wallet has sufficient funds and the transaction was signed by a passport
5. The blockchain technology must not have a single point of failure

A.1.2. Should Have

1. A voter should be able to transfer a vote to a different voter who is eligible to vote (proxy-vote)
2. The government should be able to freeze accounts
3. A transaction should be contained in a block (confirmed) within twenty seconds

A.1.3. Could Have

1. A voter could be able to use all types of identification documents without specifying which one this person is voting with

A.2. Voting station app

A.2.1. Must Have

1. There must be an option to manually input the data from the machine readable zone.
2. Reading public key from passport using NFC
3. The app must support of transaction with ePassport using NFC
4. The app must show wether the signing was succesful and if the transaction was acepted by the network.
5. The app must send a signed transaction to the blockchain.
6. The app must work on android devices running Android API level 21 and higher.

A.2.2. Should Have

1. The app should be able to show a list of transactions made with the scanned passport.
2. The app should be able to use OCR to read the ePassport's MRZ zone

A.2.3. Could Have

1. The app could have manual control for flash and focus in OCR scanning mode.

A.3. Voter app

A.3.1. Must Have

1. See current balance of voting tokens
2. Transfer tokens to another voter (proxy-voting)
3. See transaction history

A.3.2. Should Have

1. Reclaim voting token from proxy-voting

A.3.3. Could Have

1. Verify if traveling document chip is working correctly
2. Explanation of how the digital voting process works
3. Information about voter turnout
4. Information about nearest voting stations

A.3.4. Won't Have

1. Registration for digital voting
2. Local storage of voter information

B User Experience design

In order to create a smooth polling station app experience, the help of a user experience designer was offered by the client. The following user experience design emerged from a collaboration with Angelo Croes (angelo@milvum.com), UX designer at Milvum.

B.1. Polling station app - iteration 1

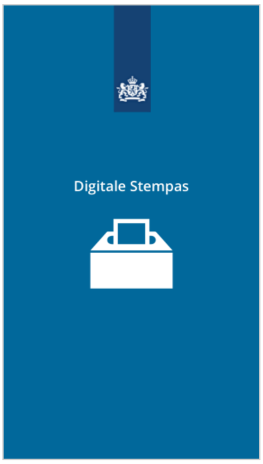
The first iteration was based on some hand drawn sketches of the workflow of the application. The designer translated this to a clickable demo, which can be found in Figure B.1.

B.2. Polling station app - iteration 2

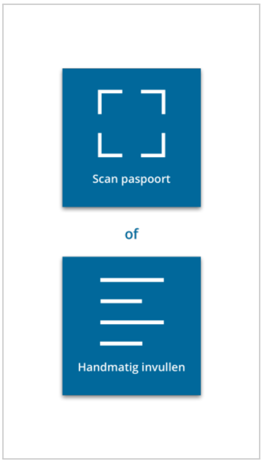
After some feedback provided was provided to the designer, e.g. the use of Material Design and the process bar while reading the NFC chip. An updated design was delivered, which can be found in Figure B.2.

B.3. Polling station app - final looks

Finally, the design was translated to an Android application by building the activities. Screenshots of the final application can be found in Figure B.3.


Digitale Stempas

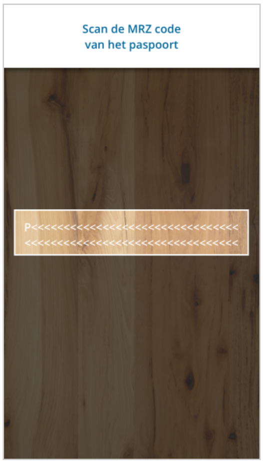
(a) Splash screen


Scan paspoort

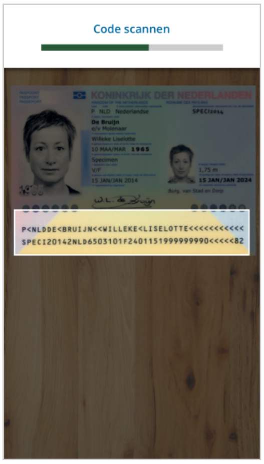
of

Handmatig invullen

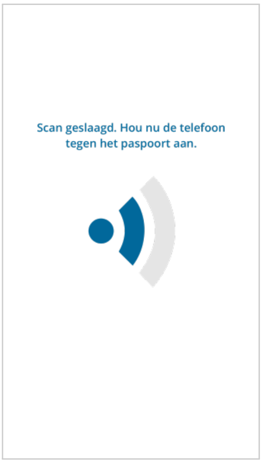
(b) Main menu


Scan de MRZ code
van het paspoort

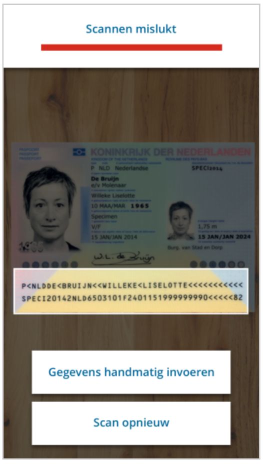
(c) OCR I


Code scannen

(d) OCR II


Scan geslaagd. Hou nu de telefoon
tegen het paspoort aan.

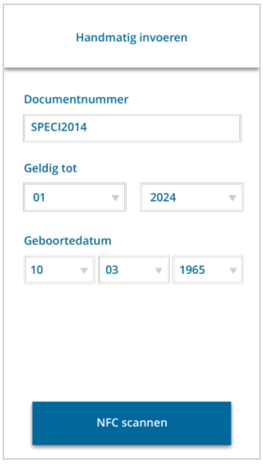
(e) NFC


Scannen mislukt

Gegevens handmatig invoeren

Scan opnieuw

(f) OCR error


Handmatig invoeren

Documentnummer

SPECI2014

Geldig tot

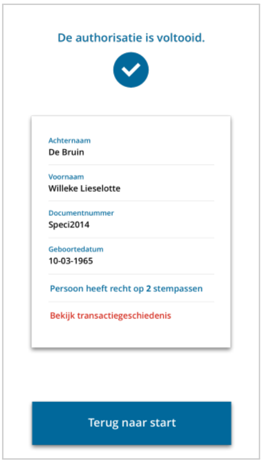
01 | 2024

Geboortedatum

10 | 03 | 1965

NFC scannen

(g) Manual input


De authorisatie is voltooid.

Achternaam
De Bruin

Voornaam
Willeke Lieselotte

Documentnummer
Speci2014

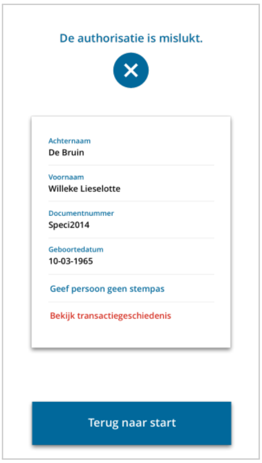
Geboortedatum
10-03-1965

Persoon heeft recht op 2 stempassen

Bekijk transactiegeschiedenis

Terug naar start

(h) Authorized


De authorisatie is mislukt.

Achternaam
De Bruin

Voornaam
Willeke Lieselotte

Documentnummer
Speci2014

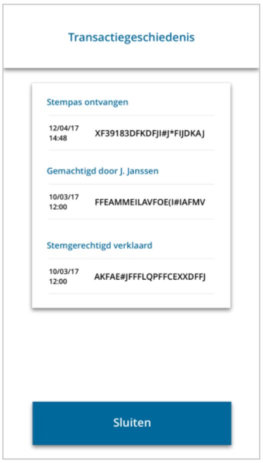
Geboortedatum
10-03-1965

Geef persoon geen stempas

Bekijk transactiegeschiedenis

Terug naar start

(i) Not authorized


Transactiegeschiedenis

Stempas ontvangen

12/04/17
14:48 XF39183DFKDFJI#J*FIJDKAJ

Gemachtigd door J. Janssen

10/03/17
12:00 FFEAMMEILAVFOE(I#IAFMV

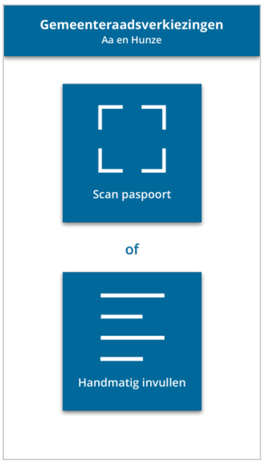
Stemgerechtigd verklaard

10/03/17
12:00 AKFAE#JFFFLQPFFCEXXDFFJ

Sluiten

(j) Transaction history

Figure B.1: Iteration 1

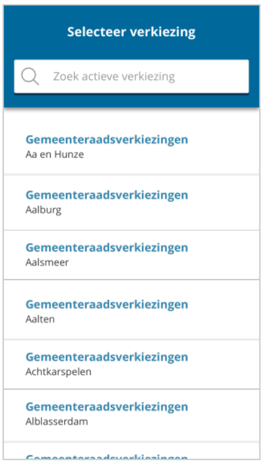

Gemeenteraadsverkiezingen
Aa en Hunze

Scan paspoort

of

Handmatig invullen

(a) Splash screen


Selecteer verkiezing

Zoek actieve verkiezing

Gemeenteraadsverkiezingen
Aa en Hunze

Gemeenteraadsverkiezingen
Aalburg

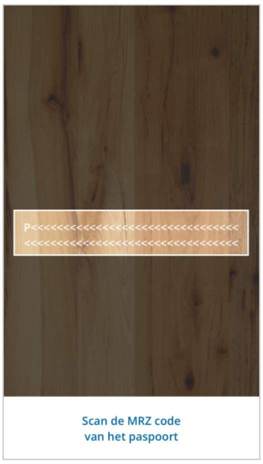
Gemeenteraadsverkiezingen
Aalsmeer

Gemeenteraadsverkiezingen
Aalten

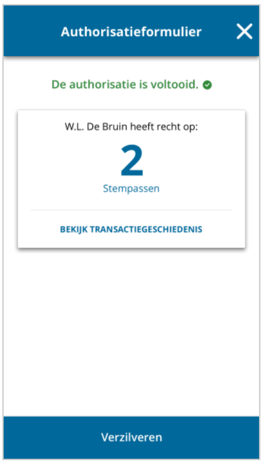
Gemeenteraadsverkiezingen
Achtkarspelen

Gemeenteraadsverkiezingen
Alblasserdam

(b) OCR error


Scan de MRZ code
van het paspoort

(c) Main menu


Authorisatieformulier

De authorisatie is voltooid.

W.L. De Bruin heeft recht op:

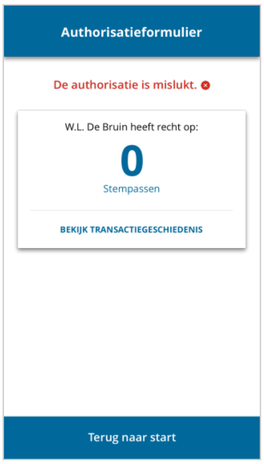
2

Stempassen

BEKIJK TRANSACTIEGESCHIEDENIS

Verzilveren

(d) OCR I


Authorisatieformulier

De authorisatie is mislukt.

W.L. De Bruin heeft recht op:

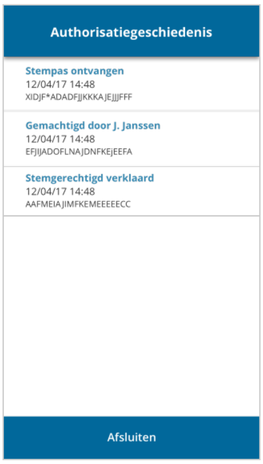
0

Stempassen

BEKIJK TRANSACTIEGESCHIEDENIS

Terug naar start

(e) OCR II


Authorisatiegeschiedenis

Stempas ontvangen
12/04/17 14:48
XIDJF*ADADFJJKKKAJEJJJFFF

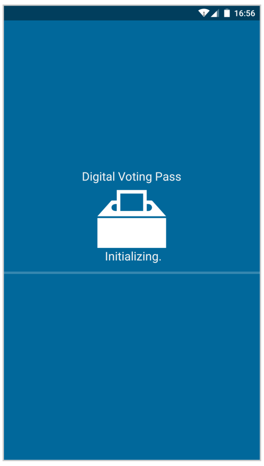
Gemachtigd door J. Janssen
12/04/17 14:48
EFJIJADOFLNAJDNFKEjEEFA

Stemgerechtigd verklaard
12/04/17 14:48
AAFMEIAJIMFKEMEEEEECC

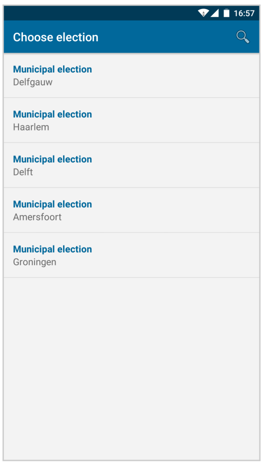
Afsluiten

(f) NFC

Figure B.2: Iteration 2



(a) Splash screen



Municipal election
Delfgauw

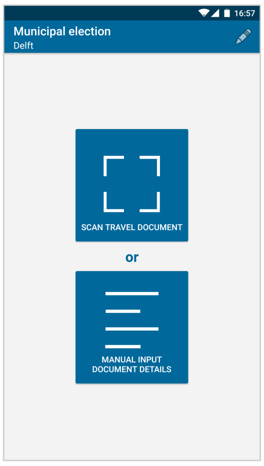
Municipal election
Haarlem

Municipal election
Delft

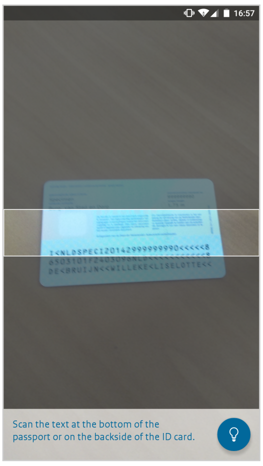
Municipal election
Amersfoort

Municipal election
Groningen

(b) Choose election

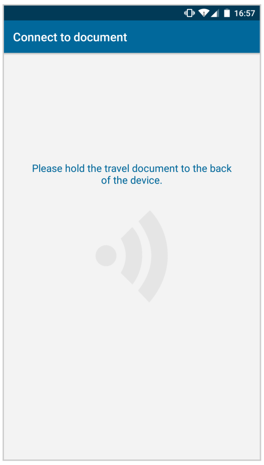


(c) Main menu



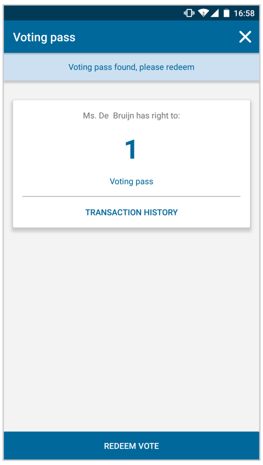
Scan the text at the bottom of the passport or on the backside of the ID card.

(d) OCR



Please hold the travel document to the back of the device.

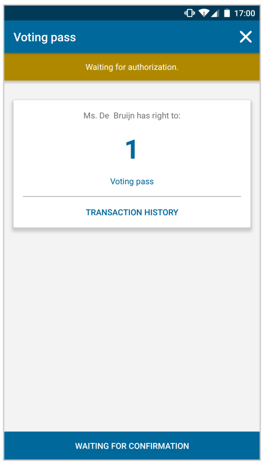
(e) NFC



Voting pass found, please redeem

Ms. De Bruijn has right to:
1
Voting pass

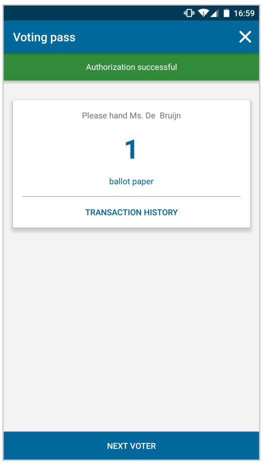
(f) Authorization succes



Waiting for authorization.

Ms. De Bruijn has right to:
1
Voting pass

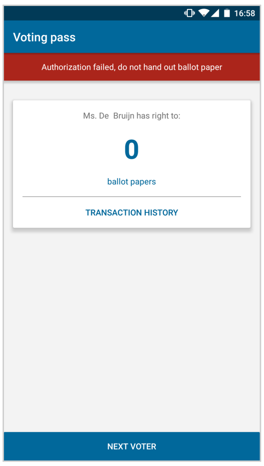
(g) Waiting for confirmation



Authorization successful

Please hand Ms. De Bruijn
1
ballot paper

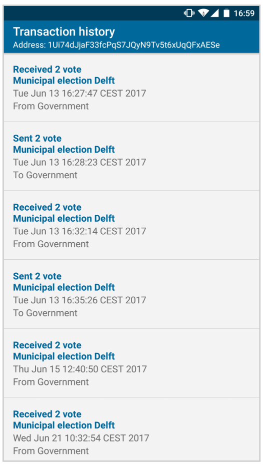
(h) Confirmed transaction



Authorization failed, do not hand out ballot paper

Ms. De Bruijn has right to:
0
ballot papers

(i) No voting passes



Transaction history
Address: 1Ui74dJjaF33fcPqS7JQyN9Tv5t6xUqQFxAESe

Received 2 vote
Municipal election Delft
Tue Jun 13 16:27:47 CEST 2017
From Government

Sent 2 vote
Municipal election Delft
Tue Jun 13 16:28:23 CEST 2017
To Government

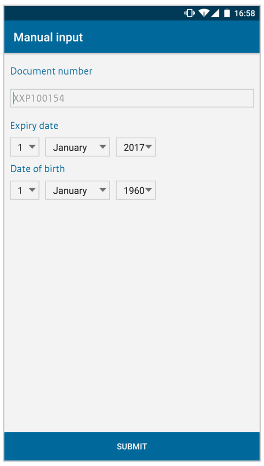
Received 2 vote
Municipal election Delft
Tue Jun 13 16:32:14 CEST 2017
From Government

Sent 2 vote
Municipal election Delft
Tue Jun 13 16:35:26 CEST 2017
To Government

Received 2 vote
Municipal election Delft
Thu Jun 15 12:40:50 CEST 2017
From Government

Received 2 vote
Municipal election Delft
Wed Jun 21 10:32:54 CEST 2017
From Government

(j) Transaction history



Document number
XXP100154
Expiry date
1 January 2017
Date of birth
1 January 1960

(k) Manual input

Figure B.3: Final result

C
Parameters

Parameter	Description	Value	Explanation
chain-protocol	Use MultiChain for a MultiChain blockchain or bitcoin for a bitcoin-style blockchain with no permissions, native assets or streams.	MultiChain	Necessary to have permissions in the blockchain
chain-description	Textual description of the blockchain for display to users.	Elections X	
root-stream-name	Name of the root stream for general data storage (leave blank for none).	root	Default
root-stream-open	Allow anyone with send permissions to write to the root stream.	true	Default
chain-is-testnet	Whether to set testnet to true in the output of various JSON-RPC API calls. This is for compatibility with Bitcoin Core and does not affect any other testnet-like behavior.	false	The blockchain should not be a test net
target-block-time	Target average number of seconds between blocks, i.e. delay for confirming transactions. If this is below 10 seconds, it is recommended to set mining-turnover low, to minimize the number of forks.	10	See subsection 4.5.2
maximum-block-size	Maximum number of bytes in each block, to prevent network flooding by a rogue miner.	1MB	Default, should be able to hold 5k transactions, see final report

Table C.1: Basis chain parameters

Parameter	Description	Value	Explanation
anyone-can-connect	Apply no restriction to connecting to the network, i.e. nodes do not require connect permissions.	true	For transparency reasons
anyone-can-send	Apply no restriction to sending transactions, i.e. signing transaction inputs.	false	Government can freeze wallets if person in question loses his right to vote, (e.g in case of incarceration or death)
anyone-can-receive	Apply no restriction to receiving transactions, i.e. appearing in transaction outputs.	true	Ability to proxy-vote
anyone-can-receive-empty	Apply no restriction to addresses which appear in transaction outputs containing no native currency, assets or other metadata. Only relevant if anyone-can-receive=false. This allows addresses without receive permission to include a change output in non-asset transactions, e.g. to publish to streams.	false	Default
anyone-can-create	Apply no restriction to creating new streams.	false	No streams, except the root stream, are used so unnecessary
anyone-can-issue	Apply no restriction to issuing (creating) new native assets.	false	Issuing means creating new election which is only reserved for the government
anyone-can-mine	Apply no restriction to mining blocks for the chain, i.e. confirming transactions.	false	Mining reserved for government nodes to protect against monopoly attack
anyone-can-activate	Apply no restriction to changing connect, send and receive permissions of other users.	false	Only admin is allowed to do this
anyone-can-admin	Apply no restriction to changing all permissions of other users.	false	Obvious
support-miner-precheck	Support advanced miner permission checks by caching the inputs spent by an administrator when setting admin or mine permissions – see permissions management for more information.	true	Default
allow-p2sh-outputs	Allow pay to scripthash outputs, where the redeem script is only revealed when an output is spent. See permissions management for more information about permissions and P2SH addresses.	false	p2sh is not needed to create and send/verify transactions. This is thus an unnecessary risk (when turned on), which can be avoided.
allow-multisig-outputs	Allow multisignature outputs, where more than one address is explicitly listed in a transaction output, and a given number of these addresses are required to sign in order to spend that output. See permissions management for more information about permissions and multisig outputs.	false	Isn't needed

Table C.2: Global permissions parameters

Parameter	Description	Value	Explanation
setup-first-blocks	Length of initial setup phase in blocks. During the setup phase, the constraints specified by the other parameters in this section are not applied.	60	This does not matter since the government will send about 13 million transactions, which will create a lot of blocks
mining-diversity	Minimum proportion of permitted miners required to participate in round-robin mining to render a valid blockchain, between 0.0 (no constraint) and 1.0 (every permitter miner must participate). Unlike mining-turnover, this is a hard rule which determines whether a blockchain is valid or not.	0.75	Default
admin-consensus-admin	Proportion of permitted administrators who must agree to modify the admin privileges for an address, between 0 (no consensus required) and 1 (every admin must agree).	1	All admins for safety
admin-consensus-activate	Proportion of permitted administrators who must agree to modify the activate privileges for an address, between 0 and 1.		Value
admin-consensus-mine	Proportion of permitted administrators who must agree to modify mining privileges for an address, between 0 and 1.	1	All admins agree for safety reasons
admin-consensus-create	Proportion of permitted administrators who must agree to modify stream creation privileges for an address, between 0 and 1.	1	There is only stream, and no more. So default one
admin-consensus-issue	Proportion of permitted administrators who must agree to modify asset issuing privileges for an address, between 0 and 1.		Value

Table C.3: Consensus parameters

Parameter	Description	Value	Explanation
lock-admin-mine-rounds	Ignore forks that reverse changes in admin or mine permissions after this many (integer) mining rounds have passed. A mining round is defined as mining-diversity multiplied by the number of permitted miners, rounded up. This prevents changes in the blockchain's governance model from being reversed and can be overridden by each node using the lockadminminerounds runtime parameter.	10	Default value
mining-requires-peers	A node will only mine if it is connected to at least one other node. This is ignored during the setup phase or if only one address has mine permissions, and can be overridden by each node using the miningrequirespeers runtime parameter.	true	An isolated node mining is useless to the network
mine-empty-rounds	If there are no new transactions, stop mining after this many rounds of empty blocks. A mining round is defined as mining-diversity multiplied by the number of permitted miners, rounded up. This reduces disk usage in blockchains with periods of low activity. If negative, continue mining indefinitely. This is ignored during the setup phase or if target-adjust-freq>0, and can be overridden by each node using the mineemptyrounds runtime parameter.	5	No mining needed when there is no election in progress or no passes being cashed,
mining-turnover	A value of 0.0 prefers pure round robin mining between an automatically-discovered subset of the permitted miners, with others stepping in only if a miner fails. In this case the number of active miners will be mining-diversity multiplied by the number of permitted miners, rounded up. A value of 1.0 prefers pure random mining between all permitted miners. Intermediate values set the balance between these two behaviors. Lower values reduce the number of forks, making the blockchain more efficient, but increase the level of mining concentration. Unlike mining-diversity, this is a recommendation rather than a consensus rule, and can be overridden by each node using the miningturnover runtime parameter.	Value	Must be low to reduce forks

Table C.4: Mining runtime parameters

Parameter	Description	Value	Explanation
skip-pow-check	Skip checking whether block hashes demonstrate proof of work.	false	Obvious
pow-minimum-bits	Initial and minimum proof of work difficulty, in leading zero bits. (1 - 32)	4	Should be low so it easy to mine a block and thus conform transactions
target-adjust-freq	Interval between proof of work difficulty adjustments, in seconds, if negative - never adjusted. (-1 - 4294967295)	-1	Difficulty should not increase, to ensure blocks are still mined fast enough
allow-min-difficulty-blocks	Allow lower difficulty blocks if none after 2*.	false	Difficulty is already low, so this is not necessary

Table C.5: Advanced mining parameters

Parameter	Description	Value	Explanation
only-accept-std-txs	Only accept and relay transactions which qualify as ’standard’.	true	Default
max-std-tx-size	Maximum size of standard transactions, in bytes. (1024 - 100000000)	Value	
max-std-op-returns-count	Maximum number of OP_RETURN metadata outputs in standard transactions. (0 - 1024)	10	Default
max-std-op-return-size	Maximum size of an OP_RETURN metadata output in a standard transaction, in bytes.	2097152	Default
max-std-op-drops-count	Maximum number of inline OP_DROP metadata elements in a single output in standard transactions.	5	Default
max-std-element-size	Maximum size of data elements in standard transactions, in bytes.	8192	Default

Table C.6: Standard transaction definitions

D

Test plans

D.1. Passport connection

For each release to the master branch the following steps must be taken to ensure the connection with the passport still works as intended.
Do all of the below for a Dutch passport and a Dutch ID card, both issued after March 9th 2014. The whole test suite should be done on two different devices in order to uncover device specific issues.

Successful connection

1. Start up the app
2. Wait for the app to be initialized
3. Choose an election
4. Press manual input button
5. Put in the document details of the travel document and submit
6. Start connection
7. Hold travel document to back of phone
8. Wait until the passport connection is completed
9. **The authorization screen should be showed**

D.1.1. Bad BAC Key

1. Start up the app
2. Wait for the app to be initialized
3. Choose an election
4. Press manual input button
5. Put in wrong document details and submit
6. Start connection
7. Hold travel document to back of phone
8. **The passport connection should fail and display an error indicating the document details are wrong**

D.1.2. Bad NFC connection

1. Start up the app
2. Wait for the app to be initialized
3. Choose an election
4. Press manual input button
5. Put in the document details of the travel document and submit
6. Start connection
7. Hold travel document to back of phone for a very short time failing the passport connection
8. **An error indicating to retry holding the travel document to the phone should be displayed.**

D.2. ePassportChain

This test plan describes how ePassportChain must be tested after each change. To following steps should be performed:

1. Create a new ePassportChain: *./multichain-util create NAME*
2. Start the daemon: *./multichaind NAME*
3. Open an CLI which is connected to the new chain: *./multichain-cli NAME*
4. Get the address which able to create an asset with *listpermissions issue*, call the obtained address X
5. Create a new asset with: *issue X asset 1000 1*
6. Create a new address: *getnewaddress* call this address Y
7. Give this address receive permissions: *grant X receive*
8. Send a token from X to Y: *sendasset Y asset 1*

If any of these commands fail, the changes have broke something and further inspections is necessary.

E
Research report

E.1. introduction

Currently, voting in the Netherlands is done in an old fashioned way, by paper and pencil. However, there is a strong call for digital voting systems from municipalities in the Netherlands, according to a survey by the public news organization NOS[1]. Propositions for digital voting are often met with scepticism, because people have major security concerns with digital voting [68]. The goal of this project is to implement a digital alternative for the paper voting pass, this system must make use of blockchain technology. With this digital voting pass voters must at least be able to do the same things as with the paper variant. The digital system should improve the voting process for voters in some way, so voters will have some incentive to switch to the new system. If voters have objections to the system it is highly unlikely that it will be implemented, so gaining the approval of voters for the system is a key aspect. This approval consists of two parts: usability or ease-to-use and trust that the system is secure. Since the lives of people involve many digital solutions, it is likely that in the future a cumbersome paper voting process could invoke more frustration with the elections and in the worst case even cause people to refrain from casting their vote. A digital solution should make voting easier and prevent voting from becoming old-fashioned or outdated. Furthermore since elections have major influence on the lives of people, they should trust that the system won't be defrauded. The scope of the project is limited to replacing the voting pass for two reasons: to be able to finish the project within 10 weeks and to give the possibility for the government to set at least a small step in the direction of a fully digital voting process.

During the first days of the project we determined the rough requirements of the project and from that derived the research subjects that are discussed in this report. More information about these first days can be found in the Project Plan. These first days also resulted in the following research question which this report answers. *How can the paper voting pass in the Dutch voting system be replaced by a secure, trustworthy, and easy-to-use digital system?* Multiple architectural choices are considered and substantial decisions are made, this report elaborates these decisions and concludes the research phase of the project.

E.2. Current Dutch voting system

In order to better understand the setting of the problem, this section will give a short outline of how the Dutch voting system currently works.

A few weeks before the election day municipalities send voting passes to a voter's home address. These arrive at least 14 days before the election. Every Dutch citizen of 18 years and older is eligible to vote for Dutch and European elections, with exception of people whose voting rights have been revoked by a judge. Revoking people's voting rights rarely happens, at the start of 2016 the voting rights of a total of 56 people had been revoked [58].

If a voter is not able to cast his vote himself, he can authorize another voter to vote on his behalf, this is called proxy-voting. There are two ways to do this:

1. For votes who live in the same municipality: by filling in the back side of the voting pass

[1]http://nos.nl/artikel/2165112-gemeenten-willen-graag-terug-naar-computerstemmen.html

2. For voters who live in different municipalities: by requesting a proxy-voting pass from the local municipality

A voter can only cast votes for himself and a maximum of two other people [79].
On election day, a voter brings his voting pass and his identification card to a polling station. Here, this person's identity is checked and if all is in order. The voter exchanges the voting pass for a ballot paper on which he marks his vote. At the end of election day all votes are counted by hand and the results are announced [80].

E.3. Existing digital solutions

In the past and present digital voting is practiced around the world by different governments. This section discusses some digital voting technologies and list advantages and disadvantages of these techniques.
In the first digital voting technique, voters come to a polling station and use a punch card to cast their vote [53]. The punch card has several ballot positions, where each positions represents a pre-determined candidate. A voter can use a punch device, such as a stylus, to create a hole in the card, this hole will be the vote on a candidate. A counting machine is now able to determine on which candidate, and thus also the party, has been voted. An example of such as system is Votamatic [87]. The advantage of this technique, and actually all other digital voting techniques mentioned, is that there is no need to count the vote by hand. A disadvantage is chad, chad is the chunk that is punched out of the card. If the chad is completely out of the card, the punch card is valid and a counting machine will register this vote. If this is not the case, a vote might not be registered by the counting machine and thus result in an inaccurate result [90]. In the 2000 general election a recount by hand, in Florida, was demanded by Gore (the opponent of Bush), because of chad [90].
Another technique that was used in the Netherlands, is the use of a direct-recording electronic voting system. In this system voters come to a polling station and cast a vote on a special machine [70]. Afterwards, the results of a polling station are put on a USB stick and is transported to one of the twenty locations were the results of all polling stations are counted [81]. These machines are not trusted by some people as discussed in section E.4.
In Arizona a pilot with digital voting was run [64]. In this pilot a person could register online, via Election.com, and state that he or she wants to vote online. After registration this person would receive a PIN via mail, this PIN is needed to cast this persons vote. Apart from the PIN, the person must answer two personal questions so stealing a PIN does not directly hand out a vote.
In Estonian voters can vote with their ID card. Their ID card contains a PKI (Public Key Infrastructure), this allows a person to sign a document with his ID [83]. To sign a document with an ID card, a PIN must be provided. Voters can download special software to cast their votes via the Internet. The software will ask for a persons ID and PIN, when this entered correctly a centralized server will be contacted. This server checks if this person is eligible to vote and if so return the set of candidates. The person can now cast his or her vote and the vote is send to the centralized server, where it will be stored. After this, the server returns a personal QR code. With a verification app and this QR code, a person can verify if his vote is correctly recorded. Security of this system is a controversial topic, in [83] researchers have shown that the software contains several vulnerabilities. An attacker would be able to disable voting in 75 minutes via a denial-of-service attack. Besides this, an attacker would be able to perform a shell-injection which allowed root access to centralized servers.

E.4. Trust and the old Dutch digital system

Trust is an integral component in many kinds of human interaction, and elections are no exception. Many varying definitions of trust exist, a definition applicable to this project, taken from Mui et al: "[Trust is] a subjective expectation an agent has about another's future behavior based on the history of their encounters." [72].
A voter needs to trust the system that the vote cast by him or her is actually counted and participates in the election, that no extra votes are added, and that the vote has the same value as any other vote cast by anyone else.

E.4.1. Trust issues

Some people have an instant disapproval when it comes to voting digitally [52], perhaps not without reason. In 1967 some municipalities in The Netherlands already started with using computers to vote [85], since

October 2007, voting computers are no longer in use due to lobbying of the group "Wij Vertrouwen Stemcomputers Niet" [88]. Mostly due to a security analysis that showed multiple technical issues with the used machines [1]. Issues addressed by this group included that the Nedap computers were 'non-voter verifiable', meaning that voters had no way of verifying that their vote was actually counted. In the current (paper) system this can be achieved because each voter has the right to watch while his vote is counted [69]. Another problem shown by this group relating to voting computers is that there usually is one central machine involved, that, if in control by a malicious party, could manipulate the outcome of the election [52]. Opponents of the Nedap computer also had problems with the closed source implementation they had and the non-transparent voting process [68].

E.4.2. Design philosophies

Evidently, by looking at the history of electronic voting, it can be seen that providing any digital solution to voting will be greeted with a lot of scepticism. It is clear that, in order to be trusted, a digital solution to the elections needs to be as open and transparent as possible, while still remaining secure. This transparency can be achieved by using all open source technology, both in software as in hardware and should be enough to silence sceptics and make voters trust the system. Digital voting must be voter verifiable and preferably be a decentralized implementation such as a decentralized blockchain, so that a single compromised machine does not endanger the rest of the network. End-to-end integrity checks will ensure that the correctness of the data is verified and that any anomalies will be detected, so the voters can trust the results of the elections.

E.5. Proposed solution

This section gives an outline of the proposed solution and states which questions about the implementation and technologies follow from this.

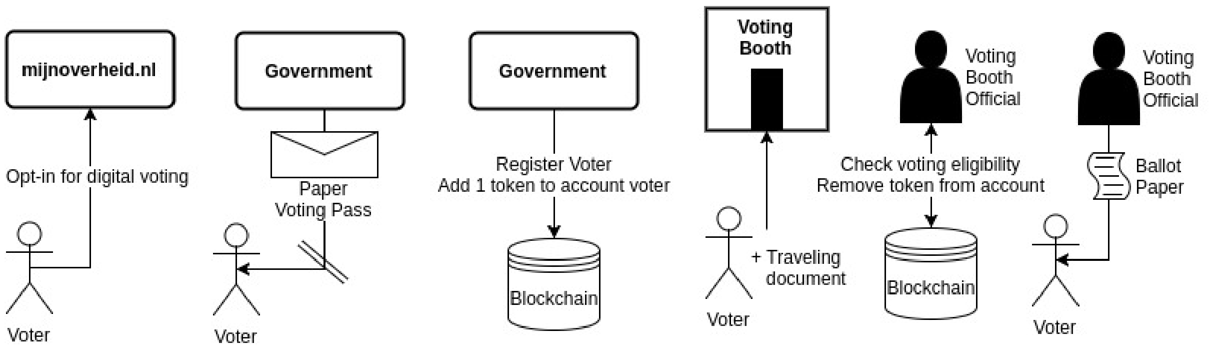


Figure E.1: Schematic rendering of the proposed system

The proposal for a solution consists of a blockchain instance that defines a vote token with a centralized owner, in Figure E.1 a visualization of the proposed voting process is given. Every person would be able to go to a government website (e.g. "MijnOverheid") and register him or herself as a digital voter. Then, this person would need to choose from a list of their identification documents that contain a contactless chip (this list is already available). There are two possible cases: Either the government knows the public key of this travel document, or not. In the second case there could be a mechanism implemented where the user must register his travel document first, this can happen remotely. At some point, for example after the digital voting registration period, the government, being the owner of the blockchain, can associate a single vote token to the accounts of registered voters.
At the time of the elections, the person would go to a voting booth and bring only the identification document that was registered. There, a voting booth official will scan his document using a NFC scanner installed on a smartphone or tablet, so the public key that corresponds to the document can be read. This app will check the chain to see if the public key still has an outstanding balance. If so, a transaction is made and signed, using the voter's document, to send the vote token to a government wallet. After this transaction is confirmed it is ensured that it was valid and a passing message would be shown on the official's device. After this, a ballot paper can be given so the person can cast his or her vote.
From this proposal questions arise about the architecture. These questions will be discussed and answered in this paper:

1. Which blockchain technology is best suited?
2. How to keep track of the identity of a voter using traveling documents?
3. How to prevent double-spending of a voting pass?
4. How to allow proxy-voting?
5. How to ensure the devices used in the voting process are secure?

E.6. Blockchain

Key aspects of blockchain technology are its decentralized network, immutability and the transparency of everything that happens on the blockchain. The decentralized structure and its structure of linked blocks of data makes it extremely hard to alter data [47]. Transparency ensures that everyone can check exactly what happened in the voting process, which makes it very hard to defraud the system without detection [57]. This makes blockchain technology very interesting to use in digital voting implementations. Transparency in the chain creates no problems for ensuring secret ballot in this project, because the transparent transaction only shows that a vote has been cast. More specifically, it only shows that a voting pass has been exchanged for a ballot paper. This physical ballot paper is used to cast the actual vote.
This section discusses which blockchain implementation would be best to use for this project and how to map the identity of the voter to an account on the blockchain so the voting eligibility of a person can be checked.

E.6.1. Blockchain implementation

There is a variety of choices for the implementation of blockchain technology in the election process. Multiple smart contracts on a chain like Ethereum or Bitcoin using Counterparty are considered[59]. Another option is setting up a blockchain for this special purpose. Such a chain could be created using MultiChain [73] or OpenChain [76]. The blockchain as implemented in Tribler, called TrustChain, was also considered [86]. Smart contracts, which have emerged in the last two years, are computerized transaction protocols which execute terms that are written in the contract [75]. These contracts can be validated by every node. Using smart contracts on a well-known and well-reviewed chain like Ethereum, which already has a large network of miners backing it, makes a monopoly attack (51% attack) unfeasible. Ethereum smart contracts have almost the same functionality as a self-made blockchain would. Custom tokens can be generated, such as in [63], which could represent whether the owner has already claimed his voting pass or not. These can be distributed from a single authority to all vote-eligible people. A problem in this set-up is that verification of the transactions will need to happen inside the smart contract, which is an expensive operation in terms of gas, Ethereum's processing fee. Our rough estimates show that it will be a few euros per verification. Furthermore, there will have to be some sort of mapping that maps private/public key pairs from the passport to key pairs on the network, this mapping would probably have to be made outside of the Ethereum network. This is necessary because the cryptographic implementations in the passport are different than in the Ethereum or Bitcoin network. Another advantage of the Ethereum network is that it is well-known and trusted, so this choice may receive less scepticism than others.
OpenChain is more like a transaction chain than a blockchain. It has no blocks but chains all transactions together. It can be anchored to the Bitcoin blockchain to benefit from the irreversibility of its Proof of Work [77]. The downside of OpenChain is that it relies on a client-server model where there is only 1 server node that verifies transactions [76]. Even though integrity can still be proven this opens up an attack surface for DDoS attacks. It this validator node is brought down, no transactions can be verified anymore and the network is halted. Since OpenChain uses a client-server model, the Java integration would be as easy as speaking to some endpoints in HTTP.
MultiChain is a toolset to easily setup a personalized blockchain, based on the Bitcoin core, that can be as private or public as needed. It features a permission system where nodes can be allowed or disallowed to do things like mining or even sending transactions. This is necessary to ensure only the government can be a mining node, otherwise a third party could supply so much processing power that it can do a monopoly attack on the network. MultiChain relies on nodes that mine in order to verify transactions [73]. This can be multiple nodes so the network is strong against DDoS attacks. MultiChain has a Java API library, but it does not seem to be finished or have very much support [71].
The advantage of using a personalized blockchain such as MultiChain or OpenChain is that those projects can be forked. Therefore the transaction signing implementation can be altered, so that it uses the same

cryptographic keys as the ePassport, eliminating the need for a mapper. This can be changed so ePassport public keys are actual wallet addresses and a transaction signed by the document could be broadcast to the network immediately. This offers great simplification compared to a setup using smart contracts.

When using existing running blockchain platforms, transaction fees apply. This includes running smart contracts on Ethereum which costs gas [61], and on the Bitcoin chain using counterparty, which costs regular transaction fees [59]. These transaction fees can be seen as paying for electricity. When the government hosts its own blockchain they would have to pay for their own electricity and hardware to keep the network online. It would be hard to analyze these costs beforehand, but since running a node or mining can be seen as the conversion of electricity to cryptocurrency [89], the costs of running a capable blockchain or paying for the smart contract are in the same ballpark. Therefore, these transaction fees play no significant role in deciding on a blockchain implementation. However, maintaining a specialized blockchain would require buying the hardware in the first place, which is costly, and additionally it would require a lot of extra processing power just to protect the network against monopoly attack.

The Tribler Multichain, also called TrustChain, is a blockchain developed by S.D. Norberhuis in a master thesis for the TU Delft. It features (near) instant verification times, each transaction is immediately put in a block in the chain. In TrustChain, nodes do not have a full copy of the chain, only of those blocks where they were one of the parties that made a transaction. Since most of the transactions will be with one party, the government, there won't be a complex network of chains so it defaults to a regular blockchain. The added benefit for voters of not having to store the entire chain is lost, since voters probably won't run their own nodes, because of issues with uptime, and the government will run the nodes for them. Crawlers can be used to verify the integrity of the chain. Using this blockchain would require taking it out of the Tribler codebase and adapting it to the needs of this project. This is considerably more effort than a solution like MultiChain or Smart contracts. In Table E.1 an overview can be found of some of the most important features that were considered for choosing a blockchain implementation.

Feature	**MultiChain**	**TrustChain**	**Smart Contract**	**OpenChain**
Confirmation times	Configurable, minimum 2 seconds	Instant	Depends on blockchain (ETH ~15sec, BTC ~10min)	Instant
Robustness / Security	Strong: decentralized, multiple government nodes	Strong: Decentralized, multiple nodes	Strong: existing network with many nodes	Questionable, single server node that does verification
Cost	Moderate, multiple verify nodes needed to protect against DDoS	Moderate, government also hosts nodes of voters	Expensive transaction fees	Cheap, single server node for verification
Language and ease of Java integration	C++ with a Java API lib	Python, in production currently	Solidity, with easy Java integration	C# with easy Java integration
Documentation	Moderate	Scarce	Lots	Moderate

Table E.1: Comparison of important features

E.6.2. Conclusion

Due to the fast reforming landscape of blockchain technologies, a right decision made today, might be completely fallacious within a short period of time. This makes it difficult to make choices based on the current available information. Is the platform still actively maintained within one year?

Based on this, the preferred choice goes to the MultiChain.com platform, because of the decentralized structure, the available API's and documentation. If this approach turns out to be suboptimal, then we might continue the project with the OpenChain platform which is not decentralized, but seems to be much easier to configure. This platform will be modified to support transaction signatures with dutch ePassports.

E.6.3. Blockchain-identity

A blockchain can be seen as a database where every move can be originated to a user. Due to this, there needs to be a solid identity which handles the access control and signs every transaction. In most cases, blockchain accounts consist out of a private and public keypair, which can be used to send and receive transactions. There is a wide range of options to store these keypairs. Bitcoin for example uses software keys which are stored in the client. This makes it vulnerable for attackers to confiscate these keys and perform unauthorized transactions. Because of this, it is desirable to store the keypair in a more secure environment.

Biometric passport key pair

Identification using PKI is something which has been implemented by several governments. For example the Belgian National Identity Card, which is introduced in 2005, contains a PKI by default [60]. This is used for signing electronic documents and logging in to several governmental services, like tax returns. There is not much criticism about the security grade of this implementation, but one of the major drawbacks of this implementation is that a specific card reader is required for these cards, which almost no citizens owned. This is the reason why it is not widely used [60].

Dutch driver's licences, identity cards and passports are designed according to the ePassport (or biometric passport) ICAO standard [82]. This means that there is an NFC-chip implemented in each of these documents which can be read with freely accessible hardware. The rise of the NFC applications in all kinds of industries, from banking to travelling has brought us to point where almost everyone has access to a reader [84].

The ICAO standard has described several obligatory and optional specifications. One of these specifications is the implementation of a so called AA (Active Authentication). This implementation consists of a private key stored into the chip which cannot be copied, a readable public key, and a signing function. This makes it possible to sign data using the private key in the chip [67].

The chip in Dutch travel documents is manufactured by a French company and is not implemented exactly the same as other European Union passports. Due to this, AA was not implemented with RSA keys, like supported by most ePassport reading libraries. After some research and different experiments it turned out that Dutch travel documents are based on ECDSA (Elliptic Curve Digital Signature Algorithm) combined with a BRAINPOOLP320r1 curve. Elliptic Curves are fortunately really common in blockchain. This makes it easier to interchange those signing mechanisms.

One major issue in this system is that this signing function is only able to sign eight bytes. A typical Bitcoin transaction has a size of 200-250 bytes [66]. Due to this, it is not possible to sign a complete transaction or a SHA-256 hash, which results in a 32 bytes hash, of it. There are also other hashing algorithms available which create smaller hashes, but they are not recommended for cryptographic usage, because of the higher risk of duplicates. To still make it possible to use the travel document for signing transactions, the signing and verifying algorithms will be modified so that they will process partial signatures of the hash. This is less secure than signing the entire hash. The next ICOA travel document standard should contain a signing method for 32 bytes to make it more secure.

Other papers discourage the use of the passport as a digital smartcard, because of the lack of any additional authentication such as a PIN [78]. This is not completely true, to have any interaction with the passport, there needs to be a Basic Access Control performed. This consist of sending a part of the MRZ (Machine Readable Zone) which is printed in the passport to the chip, so that it is guaranteed that the person accessing the data on the passport also has physical access to it.

Alternative identity solutions

If transaction signing using the ePassport proves to difficult to implement, another technique to securely sign transactions is needed. There needs to be another identity vehicle with the following specifications:

- Basic Access Control. This protects the communication between the chip and reader using encryption. Before data can be read from the chip, a key needs to be provided. In the ePassport this key consists of the date of birth, the date of expiry and the document number [67].
- A signing function. For signing data with the card itself using a private key stored inside the card. This private key is not readable from the card itself, it can only be used to sign data with the card which can then be verified. This ensures that the private key can not be stolen unless the entire document is stolen.

There are different physical smart cards available which are suitable for this purpose. A major drawback of this decision is that it is expensive and complex to provide these smart cards to the voters.

Instead of a smart card, a smartphone could also be used to sign transactions. Most devices contain a so called secure element in their hardware. This secure element makes it, like the ePassport solution, possible to sign documents using the inaccessible chip. However, the API of this secure element is not available for public usage. The app needs system level permissions to access this chip [62].
Another option is to store the key in memory of the app. In this scenario a voter would receive or generate a private key which is stored on the person's device. This private key is then used for signing transactions in the blockchain. However, a private key on a device will pose some security problems, as the private key can be stolen with malware for example. If the private key is compromised, an attacker can take away the individual's right to vote by signing away the vote token. Since the government has only distributed the tokens to addresses it knows belong to people that have signed up online and so will not receive a physical ballot paper, this attack can not add votes for a specific party. The attacker could only take ballot papers (tokens) away from voters and possibly use them himself to get extra votes for himself.

E.7. Double voting

Double voting is something that should obviously not be possible in any election system. The digital voting-pass solution should not allow this. Since it is initially assumed that the digital voting pass can be used in parallel with the paper one, it needs to be made sure that a person can not cast a vote using both systems. Obviously the digital system itself should also not allow for multiple votes to be cast by a single person (unless that person is warranted to vote for another).
If a blockchain transaction is made to resemble a person having cast his or her vote, this problem is analogous to the double spending problem. The transaction in question must first be verified in order to be sure that the voter is not trying to double-vote. Only after it is verified that the person had not already cast a vote, a ballot paper can be handed out. This verification time should be considered when choosing a blockchain platform, because waiting a long time at the voting booth is very impractical.
This waiting time is a direct result of the blockchain's choices for block generation time. Since these shorter confirmation times also allow for faster transactions in crypto-currencies which is desirable, one can expect that these delays will only decrease over time. Furthermore there are other blockchain technologies which make use of (near) instant verification, so verification time can be considered as a non-issue.

E.8. Proxy-voting

Because the digital voting pass should be a complete replacement of the paper voting pass, proxy-voting should be possible with the digital voting pass. A short description of proxy-voting can be found in section E.2.

E.8.1. Problems and constraints

Dutch law and the characteristics of proxy-voting raises certain problems that the system has to deal with.
A big issue with proxy-voting is checking if someone freely approved of giving someone else authority to vote on his behalf. There are two constraints against forcing proxy-voting in the current system that are important to note:

- A signed voting pass and a copy of an ID card are required [50]
- It is illegal to force someone to authorize another person to vote for him and to actively recruit for proxy-voting [51]

The digital system should at least give the same protection as the current system, and should strive to give better protection.
Death of voters poses another issue. When a voter dies, his voting pass is rendered invalid [49]. The unique identifier of his voting pass is then put on a list of invalid voting passes and no one will be able to cast a vote with his voting pass. The digital solution should propose a way to render votes invalid, even when they are transferred to another person. If the proxy-voter dies the proxy-votes should be returned to their original owner.
In the current system a warranter can revoke the proxy-voter's right to vote on his behalf if the proxy-voting is done by handing over a voting pass. If the proxy-voting is done via a written request at the local municipality, this is not possible. The digital system should provide a way to revoke the proxy-voting rights.

E.8.2. Possible solutions

When creating a cryptocurrency, either an entire new network or a cryptocurrency based an existing blockchain like Ethereum, it is possible to set certain restraints on the network. In the system it can be controlled how many coins are handed out, but also some transaction constraints like a maximum wallet size, which in turn can limit the amount of proxy-votes a person can cast. Disabling authorization of proxy-voting a few days before election day makes it easier to detect if votes were somehow stolen. Proxy-voting for someone in another area with local elections won't be possible, since each local election would correspond to a different system. This is also not possible in the current voting system, because by law a proxy-voter is required to cast his own vote at the same time as the proxy-vote, which wouldn't be possible if the votes are for different local elections.

E.8.3. Proposed systems

There are multiple ways to implement a voting pass solution in a current blockchain technolgies. In this section the pros and cons of three approaches will be compared.

Proxy-voting via regular transactions
The simplest system for proxy-voting is regular transactions of crypto-currencies.
In crypto-currencies like Bitcoin and Ethereum the basics of the transaction of a 'coin' or token come down to the following. A token is transferred from one owner to another. A transaction uses the previous transaction of the token and the public key of the receiving party in a hash. The sender signs this hash with his private key. This allows the system to check if the sending party is actually the owner of the token. Because a hash of the previous transaction of the token is included in the new transaction, the token can be tracked [74, 89].
This transaction system can be used for proxy-voting. Let us say someone we will call Voter 1 (V_1) would like to authorize a friend, Voter 2 (V_2), to vote on his behalf. He would make a simple transaction to move his voting token to the wallet of V_2. All he would need for this is the public key of V_2 and the transfer can be made. This system, however, has quite a few weaknesses.

- A person has no say in whether or not he becomes a proxy-voter, he could however decide to just not use the voting power.
- Because a transaction is a very simple and fast operation, there is not much time to think about the decision. This also leads to a higher risk of people authorizing proxy-voters under pressure.
- A person should verify manually if he submitted the right target address for the token, which could lead to errors and sending voting tokens to the wrong person.
- The token of V_1, which was sent to proxy-voter V_2, could be sent to Voter 3 (V_3). This leads to a situation where V_3 can cast a vote on V_1's behalf without his consent.
- There is no possibility to revoke the rights to proxy-vote, once a transaction is sent and accepted the original sender has no influence over the token.

The current paper system does deal with these problems and thus this digital solution can't be used as a proper replacement.

Proxy-voting with smart contracts or modified transaction functions
The way transactions work can be influenced or modified to enable the use of many more rules and constraints on transactions. This can either be done via smart contracts like the ones Ethereum uses, by modifying the transaction function, or adding specialized transaction functions to a blockchain implementation like Multichain.
Revoking proxy-voting rights - Let's say Voter 1 V_1 enters into a proxy-voting contract with V_2. This proxy-voting contract says that V_2 gets the voting token of V_1 a certain time before election day if V_1 doesn't submit some kind of objection (this could be implemented in many ways). Alternatively V_1's token can be transferred to V_2 at the start of the contract and can be transferred back when the contract is voided.
Additional verification - To prevent giving proxy-voting rights to the wrong person or V_1 giving proxy-voting rights to V_2 without consent, smart contracts can be used to implement a verification system. In this system V_2 should perform a verification action to confirm that he accepts to act as a proxy-voter, after that V_1 should confirm that he actually wants to give his voting rights to V_2.

Resending a token - To prevent V_2 from sending V_1's token to V_3, a simple addition to the contract concerning transactions is needed. This contract should check whether the sender of a token is the original owner, if this is not the case the token shouldn't be sent.
To make it easier for the user to set up proxy-voting an app should be developed, which calls the appropriate functions or creates a smart contract. This could create a vulnerability in the system when the device of a user is compromised, this could allow an attacker create a fake app which executes modified smart contracts. Some additional thought should be put into how to protect voters from this vulnerability. The upside is, that these transactions can still be traced on the blockchain and stolen tokens can be rendered invalid, just like it would happen if a paper voting pass is stolen. Thus, the integrity of the voting process wouldn't be compromised.

Voting with someone else's wallet
Another way to allow proxy-voting is to allow people to vote with the actual wallet of the warranter. This would need to be done with some kind of written statement that a person is authorized to proxy-vote. This system would mean no improvement in comparison to the current proxy-voting system. Also, depending on the implementation of the wallet/identity verification this could run into legislative issues. For example, if a wallet is recognized based on ID-card verification, as a proxy-voter, a person would need to bring the ID-card of the warranter with him, which is inconvenient for the warranter and also illegal [48]. A situation where a person can borrow the identifying markers of another person, and can basically act like he is another person, is not the right path to go down from a legal point of view.

E.8.4. Best system

Three options for implementations to allow for proxy-voting in digital voting passes were proposed. The third option, voting with someone else's wallet, is least applicable of the three choices, because of legislative and fraud issues. There would be virtually no trustworthy check to see if the warranter has actually allowed the proxy-voter to vote or if the proxy-voter just stole or copied the needed accessories for verification. This would cause people to distrust the system and therefore it would be hard to get this system widely accepted. Using regular transactions wouldn't be a proper replacement of the paper voting pass, cause of the mentioned weaknesses and problems. The option with specialized transaction functions or smart contracts expands on the regular transactions and by doing that, tackles the main issues with that option. The system does get more complex and thus has higher development cost, but since trust and precision are very important factors in a digital voting solution, this increase in development costs will be worth it. The added verification for proxy-voting and added simple revoking rights make this solution much better than regular transactions and the increased ease of use makes this an improvement to the current paper proxy-voting system. Voters don't need to bring anything else, but their travel document. This option is the way to go for the digital voting pass system.

E.9. Device security

One of the arguments against digital voting is that the devices that are used, could be tampered with. To overcome this issue, a device that is used in the voting process must be secure. Two techniques that can be used to secure a device and app are anti-tampering and obfuscation. Besides this, static analysis tools can be used to improve security.

E.9.1. Anti-tampering

Anti-tampering techniques can be used to ensure that the app itself has not been altered. Three methods that can be used are [54]:

- Verifying app sign at runtime
- Verifying the installer
- Environment checks

The first method, verifying the app sign at runtime, uses the fact that each Android app from the PlayStore should be signed with the developers private key [56]. Verifying the installer is a method that retrieves the name of the installer (such as com.android.example.app) from Android and checks this with a hardcoded value. The last method is mainly used to test if a debugger is attached to the app.

SafetyNet is an API from Android which provides access to Google services. With these services it is possible to determine the safety of a device [55]. This API can thus be used to ensure that device itself has not been tampered with.

E.9.2. Obfuscation

Since all software created in this project is open-source, reverse engineering is not needed to comprehend how the app works. This means that code obfuscation techniques are useless, but if a decision is made to switch to a closed-source application, code obfuscation is a useful technique. Two well-known obfuscators for Android and Java are DexGuard[2] and SafeGaurd[3].

E.9.3. Tools

The use of security static analysis tools can improve the security of application. These static analysis tools can find for example faults where *java.util.Random* is used instead of the more secure *java.security.SecureRandom*, or hardcoding private keys in the source code. Examples of tools that can be used are Find Security Bugs and QARK.

E.10. Glossary

Some jargon used in the Netherlands to describe items used in the voting process do not have a well-defined English translation. This short glossary defines the translations used in this report.

- ballot paper - stembiljet
- proxy-voter - gemachtigde
- proxy-voting - volmachtstemmen
- secret ballot - stemgeheim
- voting pass - stempas
- warranter - volmachtgever

[2]`https://www.guardsquare.com/en/dexguard`
[3]`https://www.guardsquare.com/en/proguard`

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F
Project plan

F.1. Introduction
To ensure a smooth collaboration with all the stakeholders involved in this project, we will describe our vision about the process of this project in this document. Also the questions we will investigate during research and requirements of the prototype are listed here.

F.2. Client
The project is an assignment provided by the company Milvum, based in The Hague. Milvum is a software development company, focused on developing apps in corporate environments. They start in July with developing a prototype for digital voting as a pilot for several municipalities in the Netherlands. This bachelor project will cover one part of the digital voting system. The results and problems encountered during the process are of interest to Milvum in their efforts to develop a prototype for digital voting later this year. Milvum provides a work area, lunch, and two developers, who can provide access to their IT-infrastructure and share insights on minor struggles during development.

F.3. Problem description
This project forms one part of digitizing the entire voting process: the voting pass. Currently people get a paper voting pass in their mail, with this pass, in combination with identification papers, they can vote. Instead of a paper voting pass, people should be able to show their voting eligibility using their phone. This project creates a full replacement for the paper voting pass. The solution should ensure that the right people vote and that they can only vote once. Furthermore the solution needs to ensure that no external parties can influence the voting system. The device needs to get a security check to ensure no malicious software is present, and the created app has not been altered by a third party. This check and the activation of the device as a voting pass needs to be done at the town hall.
Digital voting solutions are often met with misgiving, therefore trust in the system is a key issue. The project results in a prototype android app which acts as a digital voting pass. The entire system will make use of blockchain technology.

F.4. Team members
In Table F.1 all team members are listed. Most of the production will be covered by the students from Delft University of Technology. They are required to use their skillset and expertise to work to an end product in a structured way.

F.4.1. Required skills
- Java development the Android ecosystem
- Python for the backend
- Git for version control

Name	Role	Organization
Daan Middendorp	Student - Analysis and production	TU Delft
Wilko Meijer	Student - Analysis and production	TU Delft
Jonathan Raes	Student - Analysis and production	TU Delft
Rico Tubbing	Student - Analysis and production	TU Delft
Johan Pouwelse	TUD Coach	TU Delft
Salim Hadri / Arvind Jagesser	Product owner / Coach	Milvum
Michiel Hegemans	Development support	Milvum
Maarten van Beek	Development support	Milvum

Table F.1: Team members

- LaTeX for documentation

F.5. Product Requirements

Initial requirements can be found below, these requirements are derived from the project description and the first meeting with the client. More elaborate product requirements will follow from the research phase.

F.5.1. Functional requirements

- The app must keep track of the identity of the voter.
- The system must ensure that a voter does not vote more than once, either digitally, physically or both.
- The app and system must be secure.
- The app and system must be trustworthy.
- The app should allow proxy-voting to be possible.

F.5.2. Non-functional requirements

- Android app must be developed in Android Studio.
- Android app must use API 21+ (Lollipop).
- Blockchain technology must be developed in Python.

F.6. Workflow and collaboration

Below we define some agreements about the workflow and general collaboration in the project.
Meetings with coaches

- Weekly with Milvum coach
- Weekly with TU coach

Work location

- Milvum, Regulusweg 5, Den Haag

Working hours

- Normally 5 days per week 9h00-17h00

Technology supporting the workflow

- Github with Gitflow
- Waffle.io

Agile methodology characteristics

- Two-week iterations
- Daily stand-up meeting
- Meeting for iteration plan on Monday morning
- Retrospective meeting on Friday afternoon

The use of the agile methodology ensures a good overview of the state of the project. Each two-week sprint results in a working project and a chapter of the final report. Working agile creates a flexible workflow in which problems can be addressed quickly. On the first Monday of an iteration, a plan is made for how to reach the goal in the next two weeks. In the daily stand-up meetings, every group member pitches what they have done, what they are going to do, and if they encountered any problems that need to be addressed. Because of these meetings, every group member knows what the state of the project is and what his tasks are. By reflecting on the work process in the Friday retrospective meetings any issues in this regard can be dealt with swiftly so they don't hold back the project.
Gitflow and Waffle.io support the agile methodology by providing a structured way to assign tasks to group members, keep track of the state of tasks, and allow for easy collaboration between group members. Github allows for easy version control of the code, keeping track of issues with code and mapping tasks to results in code.

F.7. Code Quality

Good quality code is easier to maintain, to extent, and is less bug-prone. With trust as a key issue in this project, secure and easy-to-understand code is essential. To ensure good quality code, tests will be written for the system. Continuous integration by using Travis CI helps to detect problems with code early on. A pull-based development process with code reviews ensures understandable and qualitative code. Code submissions to SIG (Software Improvement Group) will give a good indication of the code quality compared to other systems and highlight areas where improvement is needed. The code will be written by keeping the definitions for maintainability by ISO 25010 in mind. SIG analyzes code according to these standards as well.

F.8. Research questions

From the problem description and the requirements we derived we define the following research question with sub questions that we will answer in the research report.
How can the paper voting pass in the Dutch voting system be replaced by a secure, trustworthy, and easy-to-use digital system?

- How does the current Dutch (paper) voting process work?
- What are existing digital voting systems?
- How to keep track of the identity of the voter?
- How to ensure that an individual cannot vote more than once?
- How to ensure the process cannot be manipulated by external parties?
- How to allow proxy-voting?
- How can we make the process trustworthy to sceptics?

F.9. Timeline

Deliverable	Description	ETA
Research report	Report about design decisions and an explanation why these decisions were made	8 May
Technical architecture	Architecture of all components and design choices	15 May
GUI Design	Design of the user interface made by external party	29 May
SIG upload	Code submission to SIG	Before 1 June
Prototype	Prototype showing a working digital implementation of the voting pass	19 June
SIG upload	Code submission to SIG	Before 26 June
Final report	A complete description of the whole process from begin to end according to the guidelines of the manual	26 June
End presentation	A final presentation with a description of the problem, solution, demo and afterwards questions.	Beginning of July (3-5)

Table F.2: Timeline of the project