# Security audit of the e-voting back-end

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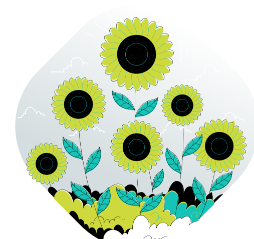

# 1 Introduction

## 1.1 Context

The goal of this audit was to examine the security of the server-side parts of the e-voting systems based on the publicly available end-to-end test system.

Swiss post publishes the end-to-end test system as a set of docker containers and configuration data[1]. This makes it possible to run a complete election event on a local machine.

Obviously, a local end-to-end system does not have all the security controls that exist in the real production environment. But since it uses the same code, it allows testing security aspects that do not depend on the production environment.

## 1.2 Execution of the work

The version of the end-to-end system that was used for this analysis was version 0.15.2.1, which was published mid of July 2022.

The tests were carried out in August and September on our premises, with the system installed on a Linux server, except for the three instances of the Secure Data Manager, which where run on a Windows machine.

We based our analysis on the following documentation (found on Swiss Post's public repository):

- Swiss Post Voting System, System Specification, v1.0.0
- Cryptographic Primitives of the Swiss Post Voting System, v1.0.0
- E-Voting Architecture Document, v.1.1.0

## 1.3 Executive summary

The analysis of the results of the tests led us to the following conclusions:

**The messages are effectively protected by signatures:** We are able to verify that all messages that are required to be signed according to the specification are indeed signed in the implementation. In two instances we verified that the modification of a message was correctly detected.

**Voters can verify that they use the correct software with the correct data:** The voters can use a published hash to verify that they are using the correct software. This software verifies all parameters, including the public key used for encryption. The verification is done with a hash of all parameters that is stored in the authenticated data of the voter's keystore. Thus when voter types in the Start Voting Key that is printed on their material, that key is used both to decrypt secret that will allow them to vote and to verify that the correct parameters will be used to vote.

[1] `https://gitlab.com/swisspost-evoting/e-voting/evoting-e2e-dev`

**Signature of parameters does not include keys:** Apart from the authenticated hash that is used to automatically authenticate all parameters, many parameters are also signed. The voters can use a published hash of the root CA certificate to verify the signatures. Besides the fact that the voter need to trust the signatures of two intermediate certificates, they can not use this method to verify the encryption keys, as these are not signed.

This means this verification thus does not conform to section 2.7.3 of the Technical requirements of the Federal Chancellery Ordinance on Electronic Voting. This is not an issue, as the authenticated hash described above fulfils the requirement.

**No technical flaws detected:** We discovered no vulnerabilities in the back-end systems that would allow an attacker to manipulate the systems.

**Some inaccuracies found in the Architectural document:** The document does not always describe the interconnections between the back-end systems exactly as they are. Moreover, the document is vague on the actual level of physical separation of the databases of the control components. This makes it more difficult to verify that the implementation respects the trust model that is described in the specification.

# 2 Channel Security Signatures

The computational proofs rely on messages' authenticity which is not given in the communication channels. To achieve this property, the cryptographic protocol adds signatures to most messages. These signatures are detailed in section 7 of the System Specification.

We set up the system in a way that we could eavesdrop on all communications and verified the presence of the signatures listed in the specification. The signatures are given in tables 16, 17 and 18 of the System Specification.

## 2.1 Configuration Phase:

| | Message Name | Signer | Recipient(s) | Message Content | Context Data |
|---|---|---|---|---|---|
| 1 | ControlComponentPublicKeys | Online $CC_j$ | Setup Comp., Auditors | $(\mathbf{pk}_{CCR_j}, \mathtt{EL}_{\mathsf{pk},j}, \pi_{\mathsf{ELpk},j})$ | (“OnlineCC keys”, $j$, ee) |
| 2 | SetupComponentVerificationData | Setup Comp. | Online $CC_j$, Auditors | $(\{\mathtt{vc}_{\mathtt{id}}, \mathrm{K}_{\mathtt{id}}, \mathsf{c}_{\mathtt{pCC,id}}, \mathsf{c}_{\mathtt{ck,id}}\}_{id=0}^{\mathtt{N_E}-1}, \mathsf{L}_{\mathtt{pCC}})$ | (“verification data”, ee, vcs) |
| 3 | ControlComponentCodeShares | Online $CC_j$ | Setup Comp., Auditors | $(\{\mathtt{vc}_{\mathtt{id}}, \mathrm{K}_{j,id}, \mathrm{Kc}_{j,id}, \mathsf{c}_{\mathsf{expPCC},j,id}, \mathsf{c}_{\mathsf{expCK},j,id}, \pi_{\mathsf{expPCC},j,id}, \pi_{\mathsf{expCK},j,id}\}_{id=0}^{\mathtt{N_E}-1})$ | (“encrypted code shares”, $j$, ee, vcs) |
| 4 | SetupComponentLVCCAllowList | Setup Comp. | Online $CC_j$ | $\mathsf{L}_{\mathtt{lVCC}}$ | (“lvcc allow list”, ee, vcs) |
| 5 | SetupComponentCMTable | Setup Comp. | Voting Server | CMtable[1] | (“cm table”, ee, vcs) |
| 6 | SetupComponentVerificationCardKeyStores | Setup Comp. | Voting Server | **VCks** | (“vc keystore”, ee, vcs) |
| 7 | SetupComponentPublicKeys | Setup Comp. | Online $CC_j$, Tally CC, Auditors, Voting Server | $(\{\mathbf{pk}_{CCR_j}\}_{j=1}^{4}, \mathbf{pk}_{CCR}, \{\mathtt{EL}_{\mathsf{pk},j}\}_{j=1}^{4}, \mathtt{EB}_{\mathsf{pk}}, \mathtt{EL}_{\mathsf{pk}})$ | (“public keys”, “setup”, ee) |
| 8 | SetupComponentTallyData | Setup Comp. | Auditors, Tally CC | $(\mathbf{vc}, \mathbf{K}, \mathsf{pTable})$ | (“tally data”, ee, vcs) |
| 9 | SetupComponentElectoralBoardHashes | Setup Comp. | Tally CC | $(\mathtt{hPW}_0, \ldots, \mathtt{hPW}_{k-1})$ | (“electoral board hashes”, ee) |

**Figure 2.1** Table 15 of the document: messages of the configuration phase

We numbered the messages from 1 to 9. We found the message 1-7 with their respective signature. Message 8 is sent to the verifier, which we did not test. Message 9 was absent due to the fact that the version of software in the end-to-end test system did not yet implement electoral board hashes.
We verified that the CMtable is correctly ordered alphabetically according to the base64 value of its first column.

## 2.2 Voting Phase:

We observed all messages with their respective signatures.

| Message Name | Signer | Recipient(s) | Message Content | Context Data |
|---|---|---|---|---|
| VotingServerEncryptedVote | Voting server | Online $\mathrm{CC}_j$ | $(\mathtt{E1}, \mathtt{E2}, \widetilde{\mathtt{E1}}, \pi_{\mathtt{Exp}}, \pi_{\mathtt{EqEnc}})$ | $(\text{“}\mathtt{encrypted\ vote}\text{”}, \mathtt{ee}, \mathtt{vcs}, \mathtt{vc_{id}})$ |
| ControlComponentPartialDecrypt | Online $\mathrm{CC}_j$ | Online $\mathrm{CC}_{j'}$ | $(\mathbf{d_j}, \pi_{\mathsf{decPCC},j})$ | $(\text{“}\mathtt{partial\ decrypt}\text{”}, j, \mathtt{ee}, \mathtt{vcs}, \mathtt{vc_{id}})$ |
| ControlComponentLCCShare | Online $\mathrm{CC}_j$ | Voting Server | $(\mathbf{lCC}_{j,\mathtt{id}}, \pi_{\mathsf{expLCC},j,\mathtt{id}})$ | $(\text{“}\mathtt{lcc\ share}\text{”}, j, \mathtt{ee}, \mathtt{vcs}, \mathtt{vc_{id}})$ |
| VotingServerConfirm | Voting server | Online $\mathrm{CC}_j$ | $\mathtt{CK_{id}}$ | $(\text{“}\mathtt{confirmation\ key}\text{”}, \mathtt{ee}, \mathtt{vcs}, \mathtt{vc_{id}})$ |
| ControlComponenthlVCC | Online $\mathrm{CC}_j$ | Online $\mathrm{CC}_{j'}$ | $\mathtt{hlVCC}_{\mathtt{id},j}$ | $(\text{“}\mathtt{hlvcc}\text{”}, j, \mathtt{ee}, \mathtt{vcs}, \mathtt{vc_{id}})$ |
| ControlComponentlVCCShare | Online $\mathrm{CC}_j$ | Voting Server | $(\mathtt{lVCC}_{\mathtt{id},j}, \pi_{\mathsf{expLVCC},j,\mathtt{id}})$ | $(\text{“}\mathtt{lvcc\ share}\text{”}, j, \mathtt{ee}, \mathtt{vcs}, \mathtt{vc_{id}})$ |

**Figure 2.2** Table 16 of the document: messages of the voting phase

## 2.3 Tally Phase:

| Message Name | Signer | Recipient(s) | Message Content | Context Data |
|---|---|---|---|---|
| ControlComponentBallotBox | Online $\mathrm{CC}_j$ | Tally CC, Auditors | $(\{\mathtt{vc_{j,i}}, \mathtt{E1}_{j,i}, \widetilde{\mathtt{E1}}_{j,i}, \mathtt{E2}_{j,i}, \pi_{\mathtt{Exp},j,i}, \pi_{\mathtt{EqEnc},j,i}\}_{i=0}^{\mathtt{N_E}-1})$ | $(\text{“}\mathtt{ballotbox}\text{”}, j, \mathtt{ee}, \mathtt{bb})$ |
| ControlComponentShuffle | Online $\mathrm{CC}_j$ | Online $\mathrm{CC}_{j'}$, Tally CC, Auditors | $(\mathbf{c}_{\mathsf{mix},j}, \pi_{\mathsf{mix},j}, \mathbf{c}_{\mathsf{dec},j}, \boldsymbol{\pi}_{\mathsf{dec},j})$ | $(\text{“}\mathtt{shuffle}\text{”}, j, \mathtt{ee}, \mathtt{bb})$ |
| TallyComponentShuffle | Tally CC | Auditors | $(\mathbf{c}_{\mathsf{mix},5}, \pi_{\mathsf{mix},5}, \mathbf{m}, \boldsymbol{\pi}_{\mathsf{dec},5})$ | $(\text{“}\mathtt{shuffle}\text{”}, \text{“}\mathtt{offline}\text{”}, \mathtt{ee}, \mathtt{bb})$ |
| TallyComponentVotes | Tally CC | Auditors | $L_{\mathsf{votes}}$ | $(\text{“}\mathtt{decoded\ votes}\text{”}, \mathtt{ee}, \mathtt{bb})$ |

**Figure 2.3** Table 17 of the document: messages of the tally phase

We observed the signatures of the two first messages. Again, the last two were not seen as they are sent to the verifier, which we did not test.

# 3 Creating error situations

We created three error scenarios to verify the correct reaction of the system.

## 3.1 Cast of a vote with an invalid pCC

One of the new features added to the protocol is an allow-list that is used by the control components to let them verify whether an input they receive for the calulation of a return code, is among all possible valid inputs. This makes sure that the control components will not participate on calculations with manipulated parameters.

We used our own voting client to submit a vote with an invalid partial choice code. As a result, we got no answer from the voting server. We also got no answer from the server when we subsequently tried to submit a correct vote with the same voting card.

The behaviour of the system is correct in the sense that a vote with invalid pCCs will be detected when the control components run the CreateLCCShare algorithm, during the calculation of the return code. Subsequent submissions of a vote are blocked because the voting card has been recorded in the list $\mathbf{L}_{\mathrm{decPCC}}$ of the card for which a pCC has already been decrypted.

We checked the logs of the e2e system to whether the absence of an answer was a correctly intercepted error or due to a crash of the program.

The error is correctly caught, as shown in the logs:

```
 $ docker logs control-component-1 | less -R
Caused by: java.lang.IllegalStateException: Failed to obtain response payload
        at ch.post.it.evoting.controlcomponents.ExactlyOnceCommandExecutor.process(ExactlyOnceCommandExecutor.java:84)
          ~[classes!/:0.15.2.1]
        [...]
        ... 13 more
Caused by: java.lang.IllegalStateException: The partial Choice Return Codes allow list does not contain the partial
Choice Return Code.
        at ch.post.it.evoting.controlcomponents.voting.sendvote.CreateLCCShareAlgortihm.createLCCShare
        (CreateLCCShareAlgortihm.java:152) ~[classes!/:0.15.2.1]
        [...]
```

## 3.2 Modifying a signed parameter

When calculating the finalisation code, the control components exchange their partial results and check that the combination of the results is in an allow-list. Only then do they reveal to the voting server the information needed to calculate the finalisation code.

In this experiment, we intercepted the traffic between the voting server and a control component. We modified the message containing the confirmation key $CK_{id}$, which is used as input for the CreateLVCC-Share algorithm. Note that this message is signed by the voting server.

The modification is detected and no finalisation code is generated. There is a timeout. The control component that received the manipulated value has the following log entry:

```
InvalidPayloadSignatureException: Signature of payload VotingServerConfirmPayload is invalid.
The signature of Long Vote Cast Return Codes Share hash response payload is invalid
```

After tallying, we can confirm that the vote is not part of the votes that have been tallied.

## 3.3 Modifying a signed parameter to create an inconsistency

In this experiment we targeted the input to the next algorithm, VerifyLVCCHash. We modified one of the hash shares that are exchanged between the control components ($\text{hlVCC}_{id}$) for validation. Note that this message is signed by the control component that sends it.

The control component that receives the modified hash, will not register the vote as confirmed in the ballot box, whereas the three other components will register it as confirmed. This leeds to the following situation:

The modification is detected and no finalisation code is generated. The control component that received the manipulated hash has the following log entry:

```
Signature of payload SetupComponentLVCCAllowListPayload is invalid
```

During the tally phase, the second control component generates the following log entry:

```
The initial ciphertexts vector and verifiable shuffles ciphertexts vector must have the same size.
```

Tallying stops.

Note that is manipulation could be done once for each control component, but on different votes. They would thus all have the same number of votes, although they would be missing a different one. This situation would not be detected by the consistency check that compares the number of initial votes with the number of shuffled votes.

It would however be detected when the control components verify the mixing proofs of the first mixing step (VerifyMixDecOnline algorithm in the system specification). Since the proofs of the first mixing step are checked against the locally stored initial list of votes ($\mathbf{c}_{\text{init},j}$), the check would fail if the control component running the check does not have the same list of votes as the first control component.

# 4 Voting client signatures and Authenticated Data

## 4.1 Certificates and signatures

When the voter accesses the home page of the voting server, a few javascript files included in the page. One of them contains the code of the voting client, that will execute the cryptographic protocol for the voter. Another file is a root certificate that is used to sign some elements that are downloaded later.

For both elements the server includes an integrity tag which lets the browser automatically check the integrity of the javascript files. Moreover, this these tags are also published on a cantonal website, to allow voter to check for themselves if the downloaded files are the intended files.

Figure 4.1 shows the relation between the elements that are downloaded in the homepage and the two successive requests to the server. The elements pointed by an arrow are signed by the element from which the arrow emerges.

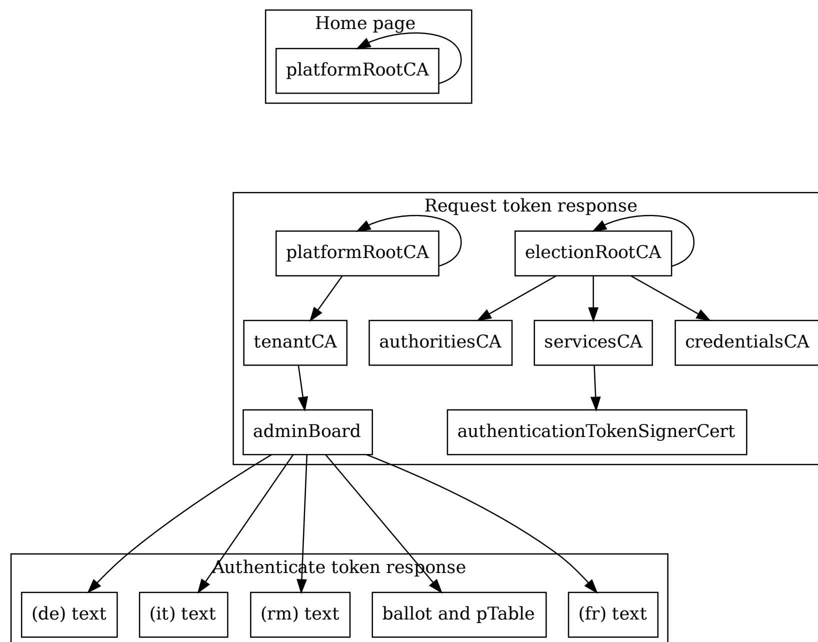


**Figure 4.1** Certificates downloaded in the first three requests, and their relation

The goal of providing a root CA with an integrity tag is to give the voter the tools needed to convince themselves that the texts of the questions and their mapping to numbers are the intended one (as listed in the pTable). As we see in figure 4.1 the platform Root CA provided in the home page does not actually sign these elements, but rather an intermediate certificate (tenantCA) that signs yet another intermediate (adminBoard) that finally signs the elements Thus, even if the voter has certainty to have the correct platform root CA, they still must trust in whoever signed the intermediate certificates.
If the certificate provided with an integrity tag in the home page had been the adminBoard certificate, then the voters would need to trust nothing else to verify the texts and the pTable.
Moreover, basic cryptographic elements like the definition of the group ($p$ and $q$) and the public key used to encrypt the votes are not signed.
Fortunately, another way has been introduced to convince the voters that all the parameters they received are authentic, as we will see in the next section.
The imperfections of the signing scheme have thus no impact.

## 4.2 Authenticated data

An alternative way of verifying the parameters received is given by the way the voter's keystore is encrypted. The keystore contains the private key that the voter needs to carry out the cryptographic protocol. The keystore is encrypted with a key derived from the Start Voting Key (SVK) that is printed on the voting material. The voter can thus only vote if they type in the correct SVK.

Additionnaly to the private key, the keystore also carries a hash of all cryptographic parameters and of the definition of the ballot. The voting client verifies that the hash matches a hash calculated with the parameters that were actually received by the client. The list of parameters that are fed into the hash are given in the GetKey algorithm of the protocol specification as seen below:

**Operation:** ▷ For all algorithms see the crypto primitives specification

1: $\mathbf{h}_{\text{aux}} \leftarrow (\text{“}\texttt{Context}\text{”}, p, q, g, \texttt{ee}, \texttt{vcs}, \text{“}\texttt{ELpk}\text{”}, \text{EL}_{\text{pk},0}, \ldots, \text{EL}_{\text{pk},\delta-1})$
2: $\mathbf{h}_{\text{aux}} \leftarrow (\mathbf{h}_{\text{aux}}, \text{“}\texttt{pkCCR}\text{”}, \text{pk}_{\text{CCR},0}, \ldots, \text{pk}_{\text{CCR},\varphi-1}, \text{“}\texttt{EncodedVotingOptions}\text{”}, \tilde{\text{p}}_0, \ldots, \tilde{\text{p}}_{n-1})$
3: $\mathbf{h}_{\text{aux}} \leftarrow (\mathbf{h}_{\text{aux}}, \text{“}\texttt{VotingOptions}\text{”}, \text{v}_0, \ldots, \text{v}_{n-1})$
4: $\mathbf{h}_{\text{aux}} \leftarrow (\mathbf{h}_{\text{aux}}, \text{“}\texttt{ciSelections}\text{”}, \texttt{ciSelection}_0, \ldots, \texttt{ciSelection}_{\psi-1})$
5: $\mathbf{h}_{\text{aux}} \leftarrow (\mathbf{h}_{\text{aux}}, \text{“}\texttt{ciVotingOptions}\text{”}, \texttt{ciVotingOption}_0, \ldots, \texttt{ciVotingOption}_{n-1})$

**Figure 4.2** List of parameters that are included in the hash which is verified when decrypting the private key of the voter (GetKey algorithm in the System Specification)

If the hashes do not match, the voting client refuses to vote. We verified this behaviour in the source code of the client and during our online test.

If the voter thus verifies the integrity of the voting client downloaded from the home page, they will have certainty that the voting client will only proceed if none of the parameters received by the server have been tampered. The more inclined voters might even be able to calculate the hash of the parameters and verify it themselves.

This authenticated hash has only been introduced in the latest versions of the protocol (1.0.0). In our opinion, this way of verifying that the parameters are authentic is superior to what is achieved by the signature scheme described in the previous section. This satisfies section 2.7.3 of the OEV that requires that voters must be able to verify that they received the correct code of the client and parameters.

# 5 Technical security tests

## 5.1 Analysis of Open Ports

All Java applications, voting server with its microservices as well as the control components, have an open port for debugging. The port gives access to the Java Debug Wire Protocol (JDWP). This protocol can be abused to execute arbitrary command on the machine.

The debugging port is activated from the command line when starting the application with the parameter:

```
-agentlib:jdwp=transport=dt_socket,server=y,suspend=n,address=*:<port>
```

This parameter is set in the common configuration file of all docker containers of the end-to-end test system, `docker-compose.common.yml`.

We assume that this parameter is not set in production environments.

Other than JDWP, which is valid in a test environment, we did not discover any unnecessary open ports.

## 5.2 Analysis of exposed REST endpoints

The different components of the back-end each offer a set of REST endpoints that are used to interact with them. For example, the `extened authentication` microservice on the voting server has an endpoint called

```
ea-ws-rest/extendedauthentication/tenant/{tenantId}/electionevent/{electionevent}/blocked
```

that can be used to get a list of cards that have been blocked because of too many failed authentication attempts.

The applications are written in Java. On startup all, endpoints and their corresponding Java method are listed in the logs of the application.

We analysed the lists of endpoints available for every service of the back-end to check if there was a service that would give access to protected information or functionality, maybe for debugging purposes. We did not identify any end-point that did not seem to be legitimate.

Note that the control components do not expose any service, they connect to a message broker, with which they can then exchange messages.

## 5.3 Scanning for vulnerabilities

The docker containers only contain the minimal set of programs needed for e-voting. We scanned the containers with a vulnerability scanner and also checked the version of some of the software manually.

All software seems to be up-to-date with no known vulnerabilities.

# 6 Documentation of the Architecture

Finally, we studied the E-Voting Architecture Document and checked if it mached the architecture found in the end-to-end testing system.

We found several inconsistencies in the document. Some of them may due to the fact that the test system is not identical to the production environment.

**5.3.1 Voter Portal:** We observed that the traffic between the Voter Portal and the Voting Server was HTTP instead of HTTPS, as shown in figure 6.

**5.4.1 SDM traffic:** Figure 8 indicates that the SDM communicates directly with the Voting Server. We observed that the SDM connects to the Voter Portal, which acts as a reverse proxy for the Voting Server.

**5.4.1 Load balancer:** Table 12 in the same section does not mention the fact that there is a load balancer between the Voting Server and the Control Components.

**5.5.1, 7.2, 7,3 Database instances:** The system architecture document seems to indicate in figure 11 and 22 and also in table 14 that there are separate databases per control component. It is not clear whether this is a logical or a physical separation. Figure 23 only shows a single Oracle database for all control components.

The documentation should be clearer about the degree of physical separation of the databases of the control components.

Although the documentation of the architecture has no direct impact on the security of the system it is important that it correctly describes the actual system. Indeed, it serves to verify that the architecture effectively corresponds to the trust assumptions on which the cryptographic protocol is based.
A precise description of the architecture is the only way to audit that the trust assumptions are met, short of a physical visit of the production environment.

# 7 Conclusions

We checked the back-end systems (Voting Server, Control Components and accessory services) for vulnerabilities or misconfigurations that would enable any attack on the cryptographic protocol.

Our tests did not reveal any weakness in the implementation of the back-end systems.

The fact that it is possible to download and run all elements necessary to cast a vote is a great way to see the code working and to interact with it. It allows carrying out tests without needing access to test systems of Swiss Post.

We found some shortcomings in the document that describes the architecture of the system, especially in the production environment. We think that it is important this document to be precise because it allows to understand if the production architecture corresponds to the trust model on which the cryptographic protocol is based.