

Zero Trust Architecture for Legal Entities

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Abstract—The European Commission is developing a European Digital Identity (EDI), which will enable trustworthy digital proof of identity for its citizens. In this thesis, we use this proof of identity in combination with cryptographic evidence of the natural person being authorized to act on behalf of a legal entity. We achieve this through trusted verifiers and the European Blockchain Services Infrastructure (EBSI). Accordingly, we provide a Zero Trust Architecture for legal entity representation, making trust portable by providing irrefutable proof of a natural person acting as a legal representative of an organization. Our Zero Trust Architecture aims to change the way we represent legal entities and delegate authorizations, making trust portable and secure. Furthermore, we provide an open standard with open-source reference implementation which is fully extendable to the forthcoming EDI. Our reference implementation focuses on creating a peer-to-peer Power-of-Attorney protocol while integrating the Member State Chamber of Commerce Company Register of the Netherlands to serve as the root of trust and the Makro as verifier. Accomplishing a legally binding delegation that is cross-border, decentralized, verifiable, has revocation, and enables management of legal delegation of authority for all EU Member States in a matter of seconds instead of weeks.

Index Terms—Power of Attorney, European Blockchain Services Infrastructure (EBSI), Decentralized Zero Trust Architecture, Self-Sovereign Identity, IPv8, Legal Entities

I. Introduction

During World War II, Allied code breakers and mathematicians, including Alan Turing, worked on deciphering encrypted messages with the utmost secrecy. Bletchley Park, where the deciphering took place, was patrolled by armed guards with strict orders to ensure the safety of the classified information and to prevent unauthorized access [1]. In essence, this meant that every individual who wished to enter the restricted area, always needed to be checked - whether they were (frequent) visitors or regular employees. The zero trust paradigm of security takes inspiration from this model for authorization, where no user, device, or application is trusted implicitly, and access controls are in place to ensure persistent

security [2]. This approach is becoming increasingly important as traditional perimeter-based security solutions are no longer sufficient to protect against exploits and data breaches in modern computer science domains. Examples include the high occurrence of identity theft: in 2018, the U.S. Department of Justice reported 16.3 million victims of identity theft [3], while in the Netherlands around 110 thousand cases of identity theft were reported in 2021 [4]. The consequences of these breaches have made ‘unauthorized access’ a very topical subject. At the same time, the European Commission is advocating a data economy in which users are controlling their own data [5, 6], whereby the intention is to oppose Big Tech’s control on online identity [7] and the associated induced privacy issues [8].

For these reasons, the European Union will provide a mainly self-sovereign digital identity to its citizens [9]–[12]. Self-sovereign identity refers to a decentralized digital identity paradigm in which people have complete control and ownership over their personal data and how it is shared [13]. In combination with this identity, the intention thereby is to adopt cyber secure practices, such as the zero-trust architecture methodology within legal entities [14]. The implementation of the European Digital Identity will happen at the level of assurance ‘high’ of the revised eIDAS regulation [15, 16]. This means that a natural person can be identified confidently [17, 18]. We will assume that the identification process is done through a trusted identifier on the high level of assurance as described in [19] because most current EU identification processes do not meet this level and the European Digital Identity Architecture and Reference Framework requires the European Digital Identity to be at level high [20]. When this is in place, a natural person can be easily verified, expediting coherent zero-trust architectures. The assurance of the identity of a natural person is important in order to establish their authority to act on behalf of a legal entity. Currently in the Netherlands, the connection between a natural person and a legal entity is established by ‘eHerkenning’, which is

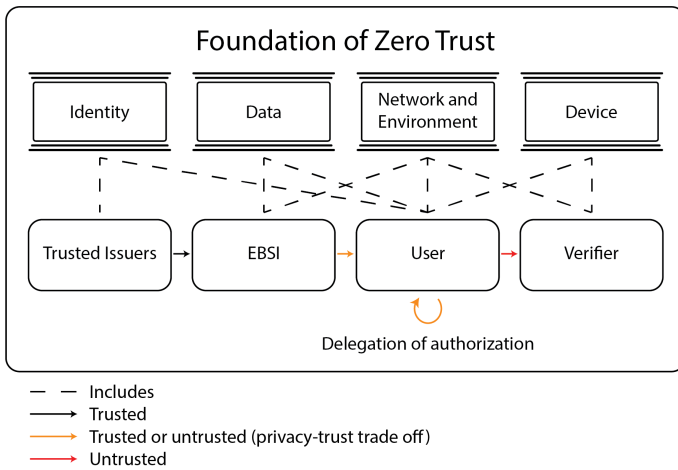


Fig. 1. Zero Trust Pillars and Architecture

a standardized login system that has been made mandatory for many entrepreneurs recently [21, 22]. However, the Dutch government is also assessing alternatives [23], due to the necessity of a more robust, efficient, and less costly manner to connect between a natural person and a legal entity. The identification of a natural person, and its subsequent connection to a legal entity, are two components that form the cornerstones of the zero-trust architecture provided in this thesis. Our zero-trust architecture is based on the pillars of the CISA Zero Trust model and applied accordingly, in order to represent legal entities in a distributed manner and ensure that data and services are not accessed by unauthorized individuals or entities [24]. The five CISA-pillars are identity, device, network & environment, application workload, and data. The application workload is however inapplicable to our model, as our solution is completely distributed. Figure 1 presents the Zero-Trust Architecture and the other four pillars. It enables users to act on behalf of a legal entity without the need for the verifier to trust the user. In this thesis, we will show that this architecture of zero trust is well-founded, verifiable, irrefutable, profoundly portable, and widely applicable.

The outline of this thesis is as follows. Section II addresses the research questions, research methodology, research boundaries, and academic relevance. Section III presents the current state of research in the area, highlighting the challenges that remain to be addressed. Consecutively, in Section IV the theoretical system design and terminology are demonstrated. Successively, Section V showcases the technical details of the implementation and presents the results. Section VI evaluates the scalability and ef-

ficiency of the system, measurements of latencies, and discusses strategies to optimize its performance. Consequently, Section VII provides a conclusion of our findings. Lastly, possible improvement and future work is provided in Section VIII.

II. Research Methodology

This study utilizes a qualitative research design to explore and analyze the zero-trust architecture paradigm and its applicability in ensuring persistent security for distributed legal entity representation. We employ a case study approach to examine a zero-trust architecture implementation of the EDI and its connection to legal entities in the Netherlands. In order for all EU Member States to benefit from our research, we provide a system architecture that can be implemented by all EU Member States. Furthermore, an open-source implementation is provided according to the given system architecture in order to research if the architecture would withstand integration. By doing this, we aim to answer whether it is possible to create a zero-trust architecture for legal entity representation which is distributed and provides irrefutable legal entity representation. Our research is scoped by topic, location, time, implementation framework, and financial resources. Firstly, the topic of the research is scoped to representing a legal entity digitally while assuming a natural person has been identified on eIDAS' assurance level high. As the research has been performed at the Delft University of Technology in cooperation with the Netherlands Chamber of Commerce, the system architecture is limited geographically to EU Member States because that is the boundary of the EBSI initiative. Regarding the implementation, the use case is limited to the Netherlands but considers cross-border functionality within the EU Member States' borders. With respect to time, the research was performed within a year such that the author could obtain the degree of Master of Science at the Delft University of Technology. Regarding to the implementation, the research is limited to the IPv8 protocol and Kotlin Superapp application developed by Delft University of Technology. Lastly, the research is financially limited as there is no budget provided. The significance of our research is in contributing guidance for zero-trust architecture implementation and making legal entity representation secure and portable. Furthermore, we exhibit possibilities for applications to the coming EDI infrastructure.

III. Problem Description

In establishing and maintaining online trust the difficulty concerns the verification of the identity of

users and entities within the digital realm. In the physical world, people can rely on visual cues and personal interactions to establish trust. Whereas in the digital world, these methods are nonexistent. Therefore, other means of establishing trust are required - not only for verification purposes, but also in order to prove a user's authority over a legal entity. With regard to the latter, there are currently various methods in order to assess whether a natural person acts on behalf of a legal entity. However, none of these methods adhere to the zero-trust architecture methodology [25]. Figure 2 represents the current ways through which a natural person can be verified by a verifier, with the purpose of allowing them to represent a legal entity. The verifier needs verify the identity of the (alleged) representative and needs to consequently consult one of the sources which could indicate that the identified person is allowed to act on behalf of the organization. The problem with the current methods of verification for proofing authority is that they are costly, untransparent, inconsistent, outdated, and rigid [26]–[28]. Furthermore, these methods are scarcely implemented outside the borders of the Netherlands. Moreover, the registration process of binding a natural person to a legal entity is only available in the Netherlands, and it is a cumbersome process that takes weeks [29]. Additionally, the centralized nature of these registries imposes security vulnerabilities. All these drawbacks have led to a lack of portability of the trust provided by the present methods. In our solution, we argue that we can make trust portable for legal entities by assuming the existence of the anticipated European Digital Identity and tackling each mentioned drawback by adhering to a decentralized zero-trust architecture.

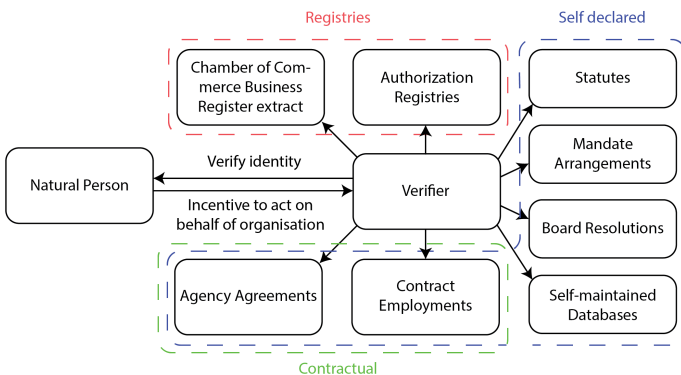


Fig. 2. Current situation of legal entity representation

IV. System Architecture

This section examines the system architecture of our decentralized peer-to-peer Zero-Trust Architec-

ture. The system architecture is intended to be an open standard for European Union member states and the next chapter contains a reference open-source implementation to demonstrate the potential implications of this open standard and the including European Digital Identity.

In Figure 1, a visualization of the open standard system architecture in relation to the pillars of the Zero Trust Architecture is provided. Our system consists of four main components: trusted issuers, the EBSI, users, and verifiers. The trusted issuers are responsible for placing verifiable credentials pertaining legal entities onto the EBSI. Thereafter, users (natural persons that want to act on behalf of a legal entity) are able to retrieve their credentials from EBSI, and if they do so directly, the credential is considered a root credential. Users may also issue credentials to other users, indicated by the orange self-loop in Figure 1. All users have the ability to present their authority to a verifier. The whole chain from a trusted issuer to a verifier is called the zero trust chain, which we will prove as the irrefutable truth in Subsection IV-E. Furthermore, all users may serve as a presenter to proof their authorization or act as a verifier to verify another user's credentials. With respect to adoption, it is up to the presenter to accept the verifier. Contrarily, it is up to the verifier to specify accepted presentations from presenters. Each of these components in the system architecture will be described in the Subsections below.

A. Power of Attorney

The representation by a natural person of a legal entity will be described as a type of Power of Attorney. A Power of Attorney (PoA) is a legal document that allows an individual or organization (the "principal") to appoint another person or organization (the "attorney-in-fact") to act on their or the companies' behalf. The attorney-in-fact is granted legal authority to make decisions and take actions on the principal's behalf, as specified in the PoA document. PoAs can be used for a variety of purposes, including financial matters, medical decisions, and legal affairs. The scope of the PoA is determined by the principal and can be as broad or narrow as they choose. In this work, all PoAs are limited to the boundaries of legal entities, and the person who is inherently authorized on behalf of a company (in the Netherlands this is the functionary enlisted in the Business Registry) is described to have full PoA over that company. Many similar interpretations of PoAs exist, e.g. delegation, mandate, authorization, and guardianship [30, 31]. The reason the term PoA is used in this work is

because, firstly, delegation is used ambiguously and may not have legal effect [32, 33]. Secondly, mandating has an alternative definition in public law¹ and moreover, the responsibility in our system should go with the attorney-in-fact, contrariwise to mandates. Thirdly, authorization is too vague and does not necessarily concern legal binding. Lastly, guardianship involves transferring all power away from a person who is unable to make decisions for themselves [34], which is inapplicable in our system as issuers will remain authorized to act.

Regarding accountability, the attorney-in-fact is expected to use due diligence and good judgment in carrying out their duties. If they fail to fulfill their responsibilities or abuse their power, they may be held accountable for their actions [35].

B. Trusted Issuers

In our Zero Trust system architecture, a trusted issuer is responsible for making the link between a natural person's identity and a legal person, such as a corporation or governmental agency. Correspondingly, trusted issuers play a critical role by providing the anchor of trust. The connection between an officer, where an officer is a user who is enlisted in a trusted issuer registry, and the legal entity at which they operate is in most EU Member States recorded at a chamber of commerce, commercial court, or governmental agency, [36] contains a complete list of such registries. These chambers, courts, and agencies are potential trusted issuers. Typically, trusted issuers only have a limited number of officers cataloged in their registry. For our architecture, this is not an issue, provided that each legal entity has at least one, which is always the case.

C. European Blockchain Services Infrastructure

The European Blockchain Services Infrastructure is a network of blockchain nodes that aims to provide a secure, reliable, and scalable infrastructure for cross-border public services in all EU Member States, Norway, Liechtenstein, and Ukraine [37, 38]. The EBSI network is based on the Hyperledger Fabric platform and utilizes a permissioned consortium model [39] of which Delft University of Technology will maintain an operational node by the end of 2023. In our system, the EBSI will function as a distributed ledger for the input of trusted issuers. Trusted issuers should register officers of legal entities in the EBSI. These registrations will become available on the EBSI in the W3C verifiable credentials format [40], achievable through the Trusted Issuer Registry API of EBSI [41].

The verifiable credential is a tailor-made credential available in EBSI's Trusted Schemas Registry [42]. In case a registration of an officer has to be revoked, this is made feasible by the Revocation and Endorsement Registry [43].

D. Users

As a user in our system, you are required to complete an onboarding process² in pursuance of binding the user's personal record to the device used by the user. Correspondingly, the process involves identifying with an EU-recognized identification document such as a passport or ID card. The enrolment must meet the "high" Level of Assurance (LoA) proclaimed in the Architecture and Reference Framework [45] and outlined in the eIDAS regulation [19, 46]. The feasibility of LoA high is a lively argument with respect to user's hardware concerns [47], privacy issues [48, 49], cross-border governmental distrust [50], and offline operability [51]. In the provided architecture we assume that personally identifiable data on LoA high is available. Nevertheless, this assumption is not strict, as the Zero Trust Architecture provided can still be operational with an already existing form of electronic identification. However, this will make the system more centralized and dependable on these services, e.g. Ireland's MyGovID, Italy's SPID, France's FranceConnect, and the Netherlands' DigiD, altering the decentralized character of this work. Acquiring personally identifiable data on the LoA high in a decentralized manner has not yet been accomplished and is outside the scope of this research. Notwithstanding, the most obvious approach to achieving this is through linking the scanned identity document to the natural person and proving its integrity with biometrics [52, 53]. Once the personally identifiable data is linked to the device of the user, the user can collect their link to a legal entity from the EBSI. Consequently, the user now possesses a digital proof of their identity and a proof of a full PoA of the legal entity they are an officer of. Combined, this empowers the user to act on behalf of the legal entity and the ability to issue PoAs to other users. Subsequently, a complete decentralized hierarchy of rights and obligations can be established, enabling any authorization connected to a legal entity anywhere at any time. While the users are in complete control of their own PoAs and their issued PoAs and are not required to trust one another. The system will contain branches and verifiable chains, which can be revoked or altered. Revocation is achieved by altering the Zero Knowledge PoA list of the corresponding

¹Article 10:10 Awb

²Specified as "enrolment" in the eIDAS regulation [44]

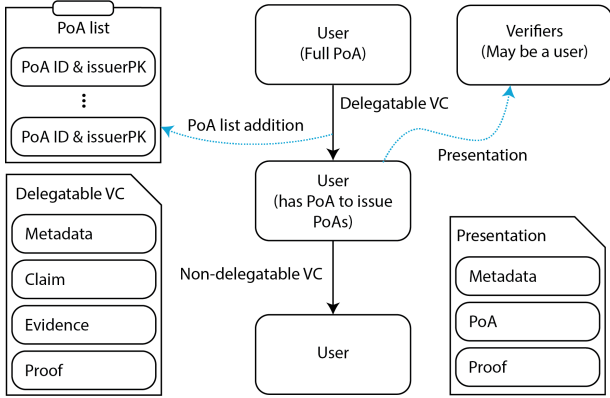


Fig. 3. Components of the Zero Trust Architecture

legal entity. Transferring a whole branch of PoAs can be altered by the principal by modifying the PoA list with a signed message. Conclusively, the user will be able to provide a presentation of their PoA which a verifier can trust. Accordingly, enabling the user to irrefutably represent a legal entity where the user sees fit.

E. Verifiers

The presentation presented by a user can be verified by a verifier, and every user within the system can act as a verifier. However, a verifier can also be an entity outside the system which happen to accept presentations from our system. The format of a PoA is a delegatable verifiable credential [54]. Upon revocation or alterations of a delegatable verifiable credential or a whole branch, the credential is added to a list and is gossiped through a network. Our Zero Trust Architecture system conjointly adheres to the Zero Knowledge Proof paradigm³ [55]. Figure 3 provides more depth to the components within the Zero Trust Architecture.

V. Evaluation

In this Chapter, we present the outcomes of implementing the Zero Trust Architecture for Legal Entities on top of TU Delft’s Decentralized Societal Infrastructure [56], further called the IDknip. This Societal Infrastructure is a decentralized platform that is designed to provide identity, trust, money, and data services. The IDknip receives the user’s identity by scanning a natural person’s identity card or passport which has been issued by a trusted

issuer. The devices in the system are operating on Android OS. The network used is the internet by IPv8 protocol, which allows for secure data sharing and communication among a network of peers [57]. In order to evaluate the performance and efficacy of this implementation in a real-world situation, we have augmented it with our own work. Our implementation enables us to evaluate the scalability and dependability of our system, in addition to identifying prospective use cases for the Zero Trust Architecture for Legal Entities.

A. European Blockchain Services Infrastructure

As shown in Figure 1, the Trusted Issuers are expected to put the credentials of owners or officers of a legal entity in the EBSI. Implementing the EBSI in a wallet is a burden as the logging is, there currently exist some wallets that are operational with the EBSI blockchain. However, most of these wallets depend on the open-source work of Walt-ID. In this work, we did not implement the integration with EBSI in our wallet, but we made a prototype of how trusted issuers should import their accreditations onto the EBSI. Accordingly, the PoA credentials are directly obtained from the Chamber of Commerce Company Registry pre-production server. To enable trusted issuers to enlist their accreditations, a verifiable credential schema should be created in the Trusted Schemas Registry. This schema contains all the information to issue a PoA to the officer of the affiliated company. In Scheme 1 is presented how the schema should look like. For trusted verifiers to put these verifiable credentials in the EBSI, they should be in the Trusted Issuers Registry. Once the trusted verifier is in this registry, the verifier can put in all the company officers. Accordingly, the user will be able to retrieve the PoA from EBSI by identifying themselves.

³The only knowledge an adversary could obtain is the number of given PoAs corresponding to a public key.

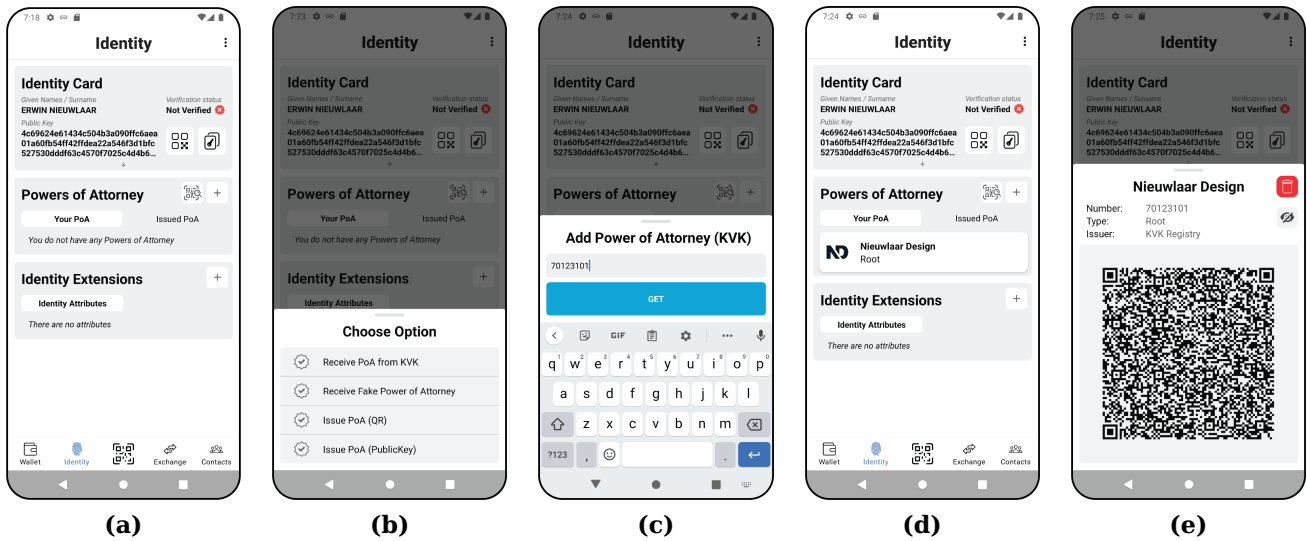


Fig. 4. Flow of obtaining Power of Attorney from the Netherlands Chamber of Commerce. **(a)** Identity fragment of the IDknip application. **(b)** Add PoA menu. **(c)** Adding PoA dialog from the Netherlands Chamber of Commerce. **(d)** Overview of the identity fragment with a root PoA obtained from the Netherlands Chamber of Commerce. **(e)** The detailed dialog of the PoA with a verifiable QR, the option to delete the PoA, and general information of the PoA.

Scheme 1. EBSI Power of Attorney Verifiable Credential

```

1 {
2   <credential-metadata>,
3   "credentialSubject": {
4     "id": "did:ebsi:bef...k21",
5     "powerOfAttorney": {
6       "id": "did:ebsi:c27...9f1",
7       "nameIssuer": "Chamber of Commerce NL",
8       "idIssuer": "59581883",
9       "type": "root",
10      "nameLegalEntity": "Nieuwlaar Design",
11      "idLegalEntityHolder": "70123101",
12      "publicKeyHolder": "4c6..c60",
13      "givenNamesHolder": "Erwin",
14      "surnameHolder": "Nieuwlaar",
15      "dateOfBirthHolder": "23-05-1994"
16    },
17   <powerOfAttorney-evidence>
18 },
19 <credential-proof>
20 }

```

As seen from the scheme, the verifiable credential consists of three parts, namely, the credential metadata, the PoA data, and the proof of the credential. The metadata and proofs are left out for a better overview, and because the verifiable credentials follow the known W3C format [40].

B. Trusted Issuer - Netherlands Chamber of Commerce

The implementation allows you to easily and securely verify your identity using your legal documents i.e. European passport or identity card. Consecutively, the user is able to obtain their PoA from the Netherlands Chamber of Commerce. The requirement is that you are registered as an officer at that legal entity. This is achieved through connecting with the HR Dataservice from the Netherlands Chamber of Commerce. To receive a signed XML from which the officers of a legal entity can be deduced. In order to access this data, a fee for start-up costs of 1040 euros and 2.40 euros for each call is required⁴ [58, 59]. In our implementation the user interacts with a pre-production server of the HR Dataservice, switching to production is a matter of paying, adding the keys, and adjusting one boolean [60]. Once successful, the user can issue PoAs to other users. Figure 4 visualizes how a root PoA can be obtained and verified by a verifier.

In Figure 4a the identity fragment is shown of the IDknip, from here the user can click the "+" sign to obtain or issue PoAs. Once clicked, the dialog 4b will show. To receive a PoA from the Netherlands Chamber of Commerce the option "Receive PoA from KVK" is chosen. Accordingly, the dialog of Figure 4c will show, where the user can fill in the Chamber of Commerce number of which the user is a registered officer in the Company Registry of the Netherlands Chamber of Commerce of that legal entity. Once filled and

⁴The price for each call will be free of charge from 2025.

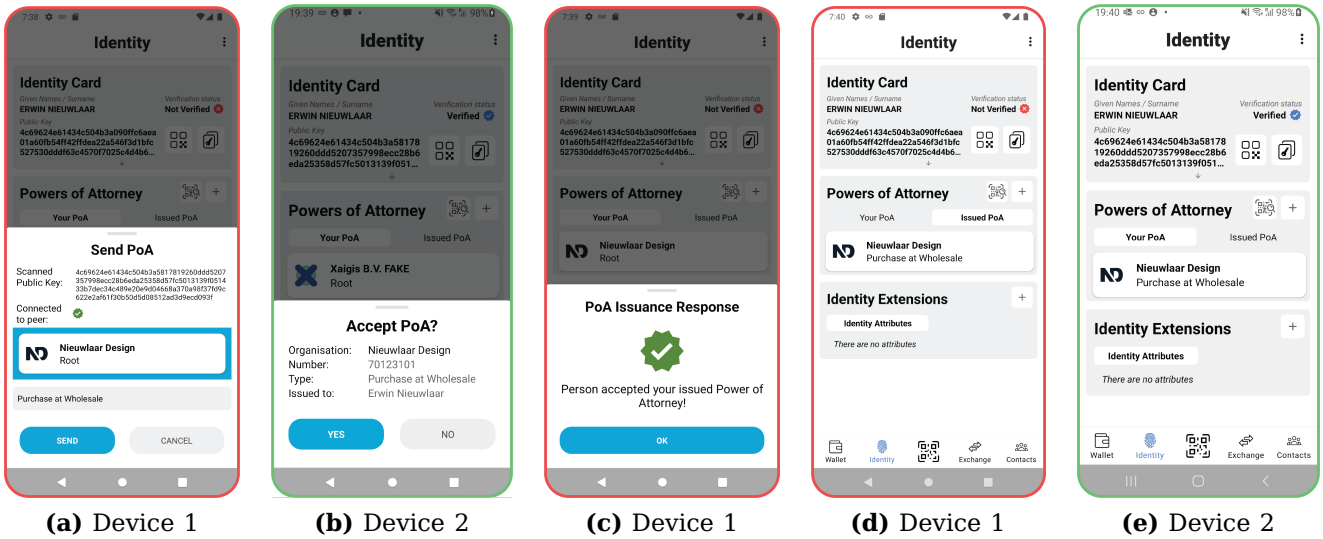


Fig. 5. Peer-to-peer issuance of a Power of Attorney. (a) Dialog to choose PoA to issue with and the PoA desired to be issued. (b) Dialog to accept receiving PoA. (c) Response of sent PoA. (d) Issued PoAs of device 1. (e) Received PoAs of device 2.

clicked upon "GET", a request with the given name, surname, birthday, and the filled legal entity number is sent to the pre-production server of the Chamber of Commerce data service. Accordingly, the Chamber of Commerce verifies if the provided legal entity indeed has a registered officer matching the given name, surname, and birthday provided by the identity of the user. When a match is found, the user will receive the PoA as can be seen in 4d. The user can click the PoA to view the detailed presentation of the PoA as shown in 4e. The detailed presentation contains general information about the PoA, the possibility to revoke or delete the PoA, and a verifiable QR code.

C. User

Once a user in a legal entity has obtained the PoA from the Netherlands Chamber of Commerce, the user is able to delegate PoAs and create a structure of authorizations. Figure 5 shows how a PoA is issued peer-to-peer from one user to another. Firstly, the user who has permission to issue PoAs will select "Issue PoA (QR)" or "Issue PoA (PublicKey)" from 4b. Once the public key is obtained successfully, the principal should choose the PoA with which they would like to issue the PoA with. Furthermore, the principal has to select the PoA it wishes to issue. The dialog to accomplish this is presented in Figure 5a. Once the PoA request is sent, the potential attorney-in-fact will receive a notification to either accept or deny the PoA as shown in Figure 5b. When the attorney-in-fact accepts the PoA, the principal will receive the issuance response shown in Figure 5c. Accordingly, the principal can view its issued PoAs from the iden-

tity fragment in the issued PoA tab as presented in Figure 5d. Lastly, the attorney-in-fact now has the authorization to purchase at wholesale as shown in Figure 5e. Within the application, any type of PoA can be created including the possibility to delegate PoAs.

D. Verifier - Makro

During a live demonstration at the Makro⁵, the Makro functioned as the verifier. The users enrolled as an officer at the Chamber of Commerce obtained their PoA credentials. Consecetevally, they could present the Makro that they are allowed to enter the Makro. Alternatively, the user that obtained the PoA credentials from the Chamber of Commerce could delegate another user a PoA. Such that the user who received the PoA could show a PoA presentation to the Makro and enter the wholesale store after presenting. The credentials were successfully implemented, and the Makro verifier was able to verify the PoA of the users accurately. This demonstration highlights the feasibility and practicality of the implementation of our zero-trust architecture for legal entities. Figure X shows a picture of the live demonstration at the headquarters of Makro.

VI. Performance Analysis

The latencies associated with loading passport data for a natural person are displayed in Figure 6. From the figure, we can observe that the latencies for reading the passport are high, ranging from 3 seconds to 6 seconds. In practise, these latencies

⁵Makro is a wholesale store in the Netherlands where only representatives of a legal entity are allowed to enter.

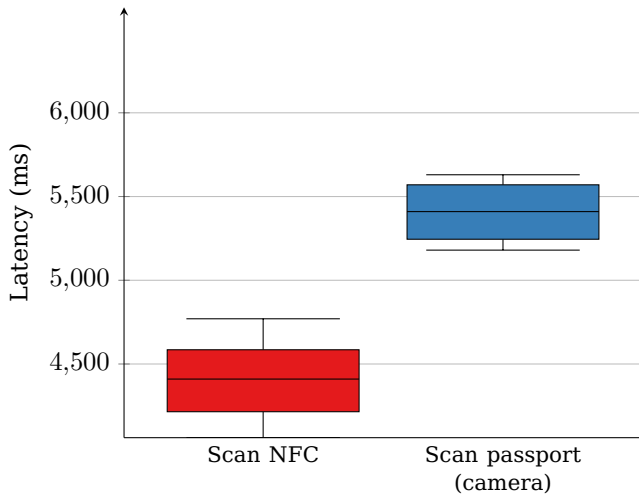


Fig. 6. Latencies reading passport data

will be even higher as user who have no knowledge of the system will scan their passports. During a live demonstration at the Chamber of Commerce, the time it took for a user to load their passport data onto IDknip was approximately 1 minute. These values indicate that the time taken to load passport data is quite significant, and could lead to a suboptimal user experience. One potential solution could involve optimizing the database queries used to retrieve passport data. A substantial amount of time is lost primarily due to users' lack of knowledge on how to scan the passport, highlighting the potential benefits of implementing a more intuitive user interface.

Figure 7 displays the network latencies associated with various operations, such as KVK requests, Issue PoA P2P requests, Revoke PoA P2P requests, and EBSI requests, for both WiFi and 4G connections. From the figure, we can observe that the network latencies are generally low for both WiFi and 4G connections, except for requests made to the KVK server. The reason for the high latency associated with KVK requests is primarily due to the large amount of data sent from the KVK server to the user. This data includes detailed information about the business or organization, and the amount of data can potentially slow down the request process, resulting in higher latencies. In contrast, the latencies associated with Issue PoA P2P requests, Revoke PoA P2P requests, and EBSI requests are relatively low, indicating that the system performs efficiently for these operations. We can also observe that the latencies are generally low for both WiFi and 4G connections, indicating that the system can handle requests made from different network connections

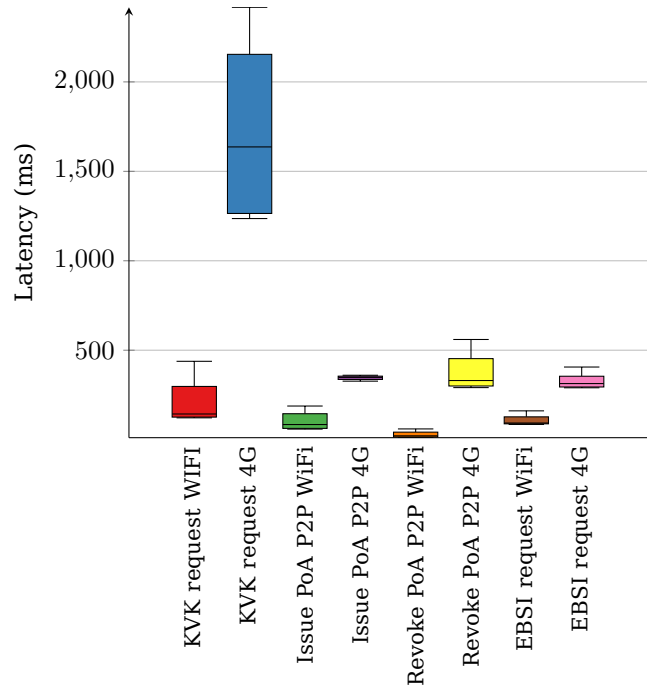


Fig. 7. Network latencies

with similar efficiency.

Furthermore, processes of the IDknip have been recorded and visualized in Flame Charts [61, 62]. The process of obtaining a PoA from the Chamber of Commerce server was recorded using a Samsung Fold 3 and is shown in Figure 8. This process was chosen as it appeared to be the heaviest of all processes in the IDknip. The whole process of obtaining a PoA from the Chamber of Commerce is also visualized in Figure 4. During the recording, the IPv8 protocol claimed some of the CPU computational power by maintaining connectivity with all of Superapp's communities as well as new peer discovery. However, we can conclude that the load of IDknip on the mobile's CPU is relatively low, as the maximum percentage of CPU utilization only reached 35% during the recordings. From Figure 8, we can observe that the process of obtaining a PoA from the Chamber of Commerce server involves multiple steps, including sending a POST request, processing the response, rendering dialogs, processing user input, and storing the PoA. The Flame Chart provides a detailed view of all the threads involved in this process, highlighting the specific components of the system that contribute to the overall latency.

VII. Conclusion

We presented a decentralized peer-to-peer Zero-Trust Architecture for EU Member States and have

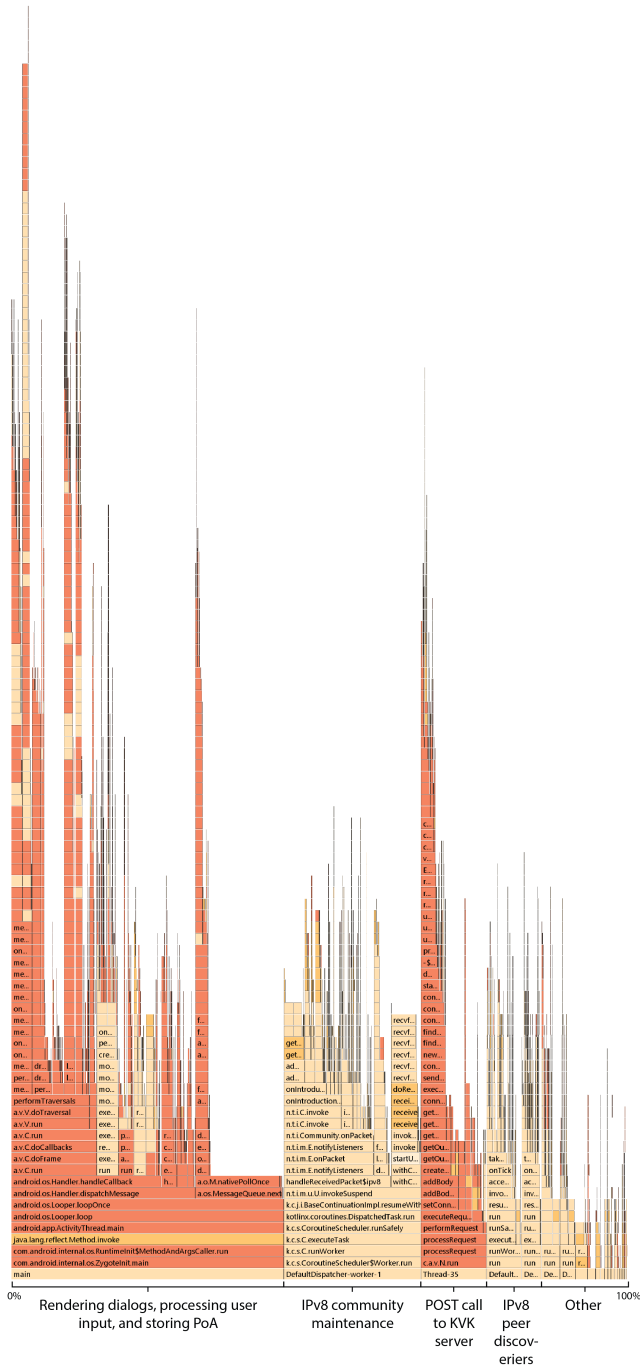


Fig. 8. Flame Chart of retrieving PoA from Chamber of Commerce

shown it to be feasible to implement in a real-world use case. The architecture is intended to be an open standard, and we provide a reference open-source implementation to demonstrate its potential implications. The components of the system architecture are in relation to the pillars of the Zero Trust Architecture paradigm. These components consist of the trusted issuers, the EBSI, users, and verifiers. The trusted issuers place verifiable credentials on the EBSI, and users retrieve their credentials from EBSI. Once a user obtains a credential from the EBSI, the user can delegate power by issuing PoAs. Accordingly, empowering natural persons to hold their credentials and decoupling from the existing ways of legal entity representation as described in the problem description. These users may present their authority to a verifier, to proof authorization to represent a legal entity irrefutably. The whole system adheres to the GDPR, revised eIDAS regulation, SSI principles, and W3C delegatable credentials standard. Integrating EBSI in the IDknip was too time-consuming, hence additional research can fulfill the complete implementation of EBSI. This would enable secure and transparent cross-border transactions, digital identity verification, and trusted authorization among the European Member states. Our architecture has the potential to provide a secure and scalable infrastructure for cross-border legal entity representation within the EU Member States.

VIII. Future Work

Future research can focus on several areas to improve the ideas and implementation provided in this thesis. Firstly, researchers can work on further refining assumptions related to the identification process of eIDAS with respect to the assurance level high, including the use of mobile technology to enhance the security and privacy of personal data [47]. Secondly, an alternative method for revocation can be developed to improve the efficiency of the revocation process and reduce message and storage complexity. Thirdly, the IDknip could be integrated with TU Delft's TrustChain, a blockchain-based system for verifying the integrity of digital data. Fourthly, exploring cross-community implementation could ensure that the IDknip can be used effectively across various communities in the IPv8 protocol enhancing scalability. Sixthly, finding ways to minimize the amount of information included in the PoA list, without compromising its integrity, can improve the Zero Knowledge methodology and the security of personal data. Fifthly, research can work on developing more information privacy in the light of delegatable Verifiable Credentials [54,

63]. Finally, maximizing the roundification of the zero-trust architecture, where data is always encrypted, can help enhance the security and privacy of the system. Researchers can look to the CISA Zero Trust Maturity Model for guidance on how to achieve this [24].

References

- [1] M. Campbell, "Beyond zero trust: Trust is a vulnerability," *Computer*, vol. 53, no. 10, pp. 110–113, 2020.
- [2] S. Rose, O. Borchert, S. Mitchell, and S. Connelly, "Zero Trust Architecture," <https://csrc.nist.gov/publications/detail/sp/800-207/final>, aug 1 2020, [Online; accessed 2023-02-22].
- [3] U.S. Department of Justice, "Victims of Identity Theft, 2018," <https://bjs.ojp.gov/library/publications/victims-identity-theft-2018>, apr 1 2021, [Online; accessed 2023-02-21].
- [4] "2,5 miljoen Nederlanders in 2021 slachtoffer van online criminaliteit," <https://www.cbs.nl/nl-nl/nieuws/2022/09/2-5-miljoen-nederlanders-in-2021-slachtoffer-van-online-criminaliteit>, feb 28 2022, [Online; accessed 2023-02-21].
- [5] Feb 2022. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1113
- [6] Nov 2020. [Online]. Available: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020PC0767>
- [7] V. Mokshagundam, "Top social login tools compared," Jan 2017. [Online]. Available: https://medium.com/@Vamshi_Mokshagundam/top-social-login-tools-compared-b350eae26118
- [8] O. Tene and J. Polonetsky, "Big data for all: Privacy and user control in the age of analytics," Apr 2013. [Online]. Available: <https://scholarlycommons.law.northwestern.edu/njtip/vol11/iss5/1/>
- [9] U. Leyen, "State of the union address by president von der leyen at the european parliament plenary," Sep 2020. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1655
- [10] P. Mart, "Is the EU Digital Identity Wallet an Implementation of Self-Sovereign Identity?" <https://thepaypers.com/expert-opinion/is-the-eu-digital-identity-wallet-an-implementation-of-self-sovereign-identity-1257448>, jul 13 2022, [Online; accessed 2023-01-26].
- [11] A. Tobin and D. Reed, "The inevitable rise of self-sovereign identity," *The Sovrin Foundation*, vol. 29, no. 2016, p. 18, 2016.
- [12] A. Mühle, A. Grüner, T. Gayvoronskaya, and C. Meinel, "A survey on essential components of a self-sovereign identity," *Computer Science Review*, vol. 30, pp. 80–86, 2018. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S1574013718301217>
- [13] C. Allen, "The path to self-sovereign identity," Apr 2016. [Online]. Available: <http://www.lifewithalacrity.com/2016/04/the-path-to-self-sovereign-identity.html>
- [14] B. GROOTHUIS, "Report on the proposal for a directive of the European Parliament and of the Council on measures for a high common level of cybersecurity across the Union, repealing Directive (EU) 2016/1148 | A9-0313/2021 | European Parliament," https://www.europarl.europa.eu/doceo/document/A-9-2021-0313_EN.html.
- [15] "Revision of the eIDAS Regulation: Findings on its implementation and application | Think Tank | European Parliament," [https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI\(2022\)69](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)69), jul 3 2022.
- [16] "Report from the commission to the european parliament and the council - on the evaluation of regulation (eu) no 910/2014 on electronic identification and trust services for electronic transactions in the internal market (eidas)," June 2021. [Online]. Available: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0290>
- [17] Feb 2022. [Online]. Available: <https://digital-strategy.ec.europa.eu/en/library/european-digital-identity-architecture-and-reference-framework-outline>
- [18] "Commission recommendation (eu) 2021/946 of 3 june 2021 on a common union toolbox for a coordinated approach towards a european digital identity framework," June 2021. [Online]. Available: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021H0946&qid=1478030835186>

- [19] The European Commission, "Article 8(3) of regulation (eu) no 910/2014 of the european parliament and of the council on electronic identification and trust services for electronic transactions in the internal market," 2015, <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R1502>.
- [20] "European Digital Identity Architecture and Reference Framework - Outline," <https://digital-strategy.ec.europa.eu/en/library/european-digital-identity-architecture-and-reference-framework-outline>, feb 22 2022.
- [21] Jun 2022. [Online]. Available: <https://deeplink.rechtspraak.nl/uitspraak?id=ECLI:NL:HR:2022:1787>
- [22] [Online]. Available: <https://www.belastingdienst.nl/wps/wcm/connect/150n0c0e-4000-4000-9000-000000000000/werk-erkenning>
- [23] M. Van Rij, "Antwoordidsinga," Jul 2022. [Online]. Available: <https://www.tweedekamer.nl/kamerstukken/kamervragen/detail?id=2022032476&doc=3622032401>
- [24] "Zero Trust Maturity Model," <https://www.cisa.gov/zero-trust-maturity-model>, 6 2021, [Online; accessed 2023-02-22].
- [25] J. Kindervag *et al.*, "Build security into your network's dna: The zero trust network architecture," *Forrester Research Inc*, vol. 27, 2010.
- [26] [Online]. Available: <https://eherkenning.nl/nl/leveranciersoverzicht>
- [27] Bram, "Ketenmachtiging bij eherkenning & digidienst," Oct 2019. [Online]. Available: <https://www.digidienst.nl/ketenmachtiging-bij-eherkenning/>
- [28] J. Patel, "Bridging data silos using big data integration," *International Journal of Database Management Systems*, vol. 11, no. 3, pp. 01-06, 2019.
- [29] "Meldingsplicht voor buitenlandse bedrijven en zelfstandigen," <https://ondernemersplein.kvk.nl/meldingsplicht-voor-buitenlandse-bedrijven-en-zelfstandigen/>.
- [30] A. Abdullah, S. den Breeijen, K. Cooper, M. Corning, O. Coutts, R. Cranston, H. Dahl, D. Hardman, N. Hickman, N. Neubauer, D. O'Donnell, P. Page, J. Phillips, D. Reed, C. Raczkowski, P. Simpson, J. Stirling, and S. Warner, "On guardianship in self-sovereign identity," *Sovrin Guardianship Task Force*, pp. 1-33, 11 2019.
- [31] J. Moye, K. Stolzmann, E. J. Auguste, A. B. Cohen, C. C. Catlin, Z. S. Sager, R. E. Weiskittle, C. B. Woolverton, H. L. Connors, and J. L. Sullivan, "End-of-life care for persons under guardianship," *Journal of Pain and Symptom Management*, vol. 62, no. 1, pp. 81-90.e2, 2021. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0885392420308750>
- [32] B. G. ALI POULADI, JAHANBAKHS GHOLAMI, "Delegation of power of attorney and identification of related legal works," *Journal of Contemporary Issues in Business and Government*, vol. 27, no. 2, pp. 1388-1390, 2021.
- [33] J. Lamb-Ruiz, "Apoderamiento: "power of attorney" vs "delegation of authority"," <https://www.proz.com/kudoz/spanish-to-english/law-contracts/702330-apoderamiento-%22power-of-attorney%22-vs-%22delegation-of-authority%22.html>, [Online; accessed 2023-01-04].
- [34] A. B. A. C. on Law, A. P. Association, and N. C. of Probate Judges (US), "Judicial determination of capacity of older adults in guardianship proceedings," in *Judicial determination of capacity of older adults in guardianship proceedings*. American Bar Association, 2006.
- [35] M. Goetting, "Power of attorney," *Revised Mar*, 2013.
- [36] "European business registers," <https://www.kvk.nl/english/about-the-netherlands-chamber-of-commerce/foreign-registers-overview/european-business-registers/>, [Online; accessed 2023-01-03].
- [37] "ukrainebsi," <https://thedigital.gov.ua/news/ukraina-priednalasya-do-evropeyskogo-blokcheyn-partnerstva-v-statusi-sposterigacha-1>, jun 17 2022, [Online; accessed 2023-01-03].
- [38] "Europeancountriesjoinblockchainpartnership," <https://digital-strategy.ec.europa.eu/en/news/european-countries-join-blockchain-partnership>, apr 10 2018, [Online; accessed 2023-01-03].
- [39] M. Turkanović and B. Podgorelec, "Signing blockchain transactions using qualified certificates," *IEEE Internet Computing*, vol. PP, pp. 1-1, 09 2020.
- [40] "Verifiable Credentials Data Model v1.1," <https://www.w3.org/TR/vc-data-model/>, mar 3 2022, [Online; accessed 2023-01-03].
- [41] "Trusted Issuers Registry API v3 | EBSI developers hub," <https://api-pilot.ebsi.eu/docs/apis/trusted-issuers-registry/latest>, [Online; accessed 2023-01-03].
- [42] "Trusted Schemas Registry API v2 | EBSI developers hub," <https://api-pilot.ebsi.eu/docs/apis/trusted-schemas-registry/latest>, [Online; accessed 2023-01-03].
- [43] "Education and Verifiable Accreditation Records - EBSI Specifications -," <https://ec.europa.eu/digital-building-blocks/wikis/display/EBSIDOC/Education+Verifiable+Accreditation+Records>, feb 22 2022, [Online; accessed 2023-01-03].
- [44] The European Parliament and the Council of the European Union, "Regulation (eu) no 910/2014 of the european parliament and of the council," 2014, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014
- [45] "The European Digital Identity Wallet Architecture and Reference Framework," <https://digital-strategy.ec.europa.eu/en/library/european-digital-identity-wallet-architecture-and-reference-framework>, feb 10 2023.
- [46] The European Commission, "The common union toolbox for a coordinated approach towards a european digital identity framework - the architecture and reference framework," December 2022, 0.1.2 Draft Version.
- [47] E. Verheul, "Secdsa: Mobile signing and authentication under classical "sole control"," Cryptology ePrint Archive, Paper 2021/910, 2021, <https://eprint.iacr.org/2021/910>. [Online]. Available: <https://eprint.iacr.org/2021/910>
- [48] M. Walsh, "The challenges facing the EU's new digital identitysystem - Raconteur," <https://www.raconteur.net/technology/problems-identified-for-new-eu-digital-identity-wallet/>, nov 7 2022, [Online; accessed 2023-01-05].
- [49] J.-H. Hoepman, "Civil liberties aspects of the European Digital Identity Framework." <https://blog.xot.nl/2022/01/31/civil-liberties-aspects-of-the-european-digital-identity-framework/index.html>, jan 31 2022, [Online; accessed 2023-01-05].
- [50] J.-S. ARRIGHI, J.-T. BATTESTINI, L. COATLEVEN, F. HUBLET, S. MARINI, and V. QUEUDET, "The Scale of Trust: Local, Regional, National and European Politics in Perspective - Groupe d'études géopolitiques," <https://geopolitique.eu/en/2022/07/13/the-scale-of-trust-local-regional-national-and-european-politics-in-perspective/>, 7 2022, [Online; accessed 2023-01-05].
- [51] D. Mekinec, "Offline face recognition: why use it? - Visage Technologies," <https://visagetechnologies.com/offline-face-recognition/>, aug 12 2022, [Online; accessed 2023-01-05].
- [52] A. Traichuk, "6 Best Open-Source Projects for Real-Time Face Recognition | HackerNoon," <https://hackernoon.com/6-best-open-source-projects-for-real-time-face-recognition-vr1w34x5>, apr 28 2021, [Online; accessed 2023-01-05].
- [53] O. B. Maestro, "Biometrics in Identity," <https://dis-blog.thalesgroup.com/identity-biometric-solutions/2022/10/27/biometrics-in-identity/>, oct 27 2022, [Online; accessed 2023-01-05].
- [54] J. Camenisch, M. Drijvers, and M. Dubovitskaya, "Practical uc-secure delegatable credentials with attributes and their application to blockchain," in *Proceedings of the 2017 ACM SIGSAC Conference on Computer and Communications Security*, ser. CCS '17. New York, NY, USA: Association for Computing Machinery, 2017, p. 683-699. [Online]. Available: <https://doi.org/10.1145/3133956.3134025>
- [55] S. Goldwasser, S. Micali, and C. Rackoff, "The knowledge complexity of interactive proof-systems," in *Proceedings of*

the Seventeenth Annual ACM Symposium on Theory of Computing, ser. STOC '85. New York, NY, USA: Association for Computing Machinery, 1985, p. 291–304. [Online]. Available: <https://doi.org/10.1145/22145.22178>

- [56] J. Bambacht, “Web3: A decentralized societal infrastructure for identity, trust, money, and data,” <https://repository.tudelft.nl/islandora/object/uuid%3A3ad68dbd-3444-4e01-94a2-d28044b0ba3f>, feb 28 2022, [Online; accessed 2023-01-08].
- [57] Tribler, “Ipv8 documentation,” 2022. [Online]. Available: https://py-ipv8.readthedocs.io/_/downloads/en/latest/pdf/
- [58] “Hoe bepalen wij onze tarieven?” <https://www.kvk.nl/over-kvk/over-het-handelsregister/tarieven/>, [Online; accessed 2023-01-08].
- [59] “Kamerbrief over voortgang Datavisie Handelsregister,” <https://www.rijksoverheid.nl/documenten/kamerstukken/2023/01/09/voortgang-datavisie-handelsregister>.
- [60] M. Mayer, “Handleiding kvk bevoegdheden,” <https://bevoegdheden.mayersoftwaredevelopment.nl/>, [Online; accessed 2023-01-08].
- [61] C.-P. Bezemer, J. Pouwelse, and B. Gregg, “Understanding software performance regressions using differential flame graphs,” *2015 IEEE 22nd International Conference on Software Analysis, Evolution, and Reengineering, SANER 2015 - Proceedings*, pp. 535–539, 04 2015.
- [62] B. Gregg, “The flame graph,” *Commun. ACM*, vol. 59, no. 6, p. 48–57, may 2016. [Online]. Available: <https://doi.org/10.1145/2909476>
- [63] J. Blömer and J. Bobolz, “Delegatable attribute-based anonymous credentials from dynamically malleable signatures,” in *Applied Cryptography and Network Security - 16th International Conference, ACNS 2018, Leuven, Belgium, July 2-4, 2018, Proceedings*, ser. Lecture Notes in Computer Science, B. Preneel and F. Vercauteren, Eds., vol. 10892. Springer, 2018, pp. 221–239. [Online]. Available: https://doi.org/10.1007/978-3-319-93387-0_12