Zero Trust Architecture for Legal Entities

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***Abstract*—The European Commission is developing a European Digital Identity (EDI), which will enable a trustworthy digital proof of identity for its citizens. We present a proof of identity in combination with cryptographic evidence of the natural person being authorized to act on behalf of a legal entity. Our study achieves this by connecting users of our system with trusted issuers, the European Blockchain Services Infrastructure (EBSI), and verifiers. 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 with Power-of-Attorneys (PoA) as a legal primitive, making trust portable and secure. With government assistance, we conducted a pilot deployment of our prototype with live connectivity to the legal source of truth, the Chamber of Commerce (KVK). In our pilot, a commercial business-only retailer acted as the verifier of the PoA. We shorten legally binding delegation that is cross-border, decentralized, verifiable, and has revocation from a week-long process to mere seconds.**

***Keywords*—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 codebreakers 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 [3]. Examples include the high occurrence of identity theft. In 2018, the U.S. Department of Justice reported 16.3 million victims of identity theft [4], while in the Netherlands around 110 thousand cases of identity theft were reported in 2021 [5]. 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 data [6, 7], whereby the intention is to oppose Big Tech's control on online identity and the associated induced privacy issues [8, 9].

Therefore, the European Union will provide a mainly self-sovereign digital identity to its citizens by 2025 [10]–[13]. 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 [14]. In combination with this identity, the intention thereby is to adopt secure cyber practices, such as the zero-trust architecture methodology within legal entities [15]. The implementation of the EDI will happen at the level of assurance 'high' of the revised eIDAS regulation [16, 17]. This means that a natural person can be identified confidently [18, 19]. We will assume that the identification process is done through a trusted identifier on the high level of assurance as described in the eIDAS regulation [20]. Currently, most EU identification processes do not meet this level and the EDI Architecture and Reference Framework requires the EDI to be at eIDAS assurance level 'high' [21]. When the EDI 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. At the moment in the Netherlands, the connection between a natural person and a legal entity is established by 'eHerkenning', which is a standardized login system that has been made mandatory for many entrepreneurs recently [22, 23]. However, the Dutch government is also assessing

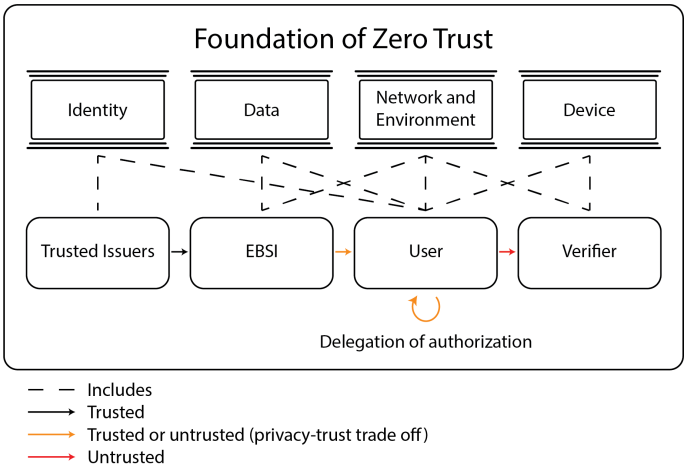

Fig. 1. Zero-Trust Architecture for Delegation

alternatives [24], due to the necessity of a more robust, efficient, and less costly manner to connect between a natural person and a legal entity. The identifying of a natural person, and its subsequent connection to a legal entity, are two components that form the cornerstones of the zero-trust architecture we provide. Our zero-trust architecture is based on the pillars of the United States' Cybersecurity and Infrastructure Security Agency (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 [25]. The five CISA-pillars are identity, device, network & environment, application workload, and data. The application workload, which is the fifth pillar of the CISA Zero Trust model, 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 paper, we will show that our zero-trust architecture is well-founded, verifiable, irrefutable, profoundly portable, and widely applicable.

The outline of this paper is as follows. Section II presents the current state of research in the area, highlighting the challenges that remain to be addressed. Section III addresses the research questions, research methodology, research boundaries, and academic relevance. Consecutively, in Section IV terminology is explained and a zero-trust architecture is proposed. Successively, Section V showcases the technical details of the implementation and presents a design of the zero-trust architecture. Section VI evaluates the scalability of the system, measurements of latencies, and discusses strategies to optimize its performance and usability. Consequently, Section VII provides a conclusion of our findings. Lastly, possible improvements and future work is provided in Section VIII.

II. Problem Description

In establishing and maintaining online trust the difficulty concerns verifying the identity of natural users and legal 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 limited to pictures or video. 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. Regarding the latter, there are currently various methods in order to assess whether a natural person acts on behalf of a legal entity. However, these methods are outside the zero-trust architecture methodology [26]. Figure 2 represents the current ways through which a natural person can be verified by a verifier, with the purpose to allow to represent a legal entity. The verifier needs to verify the (alleged) representative's identity and 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 [27]–[29]. Furthermore, these methods are scarcely implemented outside the Netherlands. Moreover, the registration process of binding a natural person to a legal entity is only available in the Netherlands, and is a cumbersome process that takes weeks [30]. 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.

III. 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

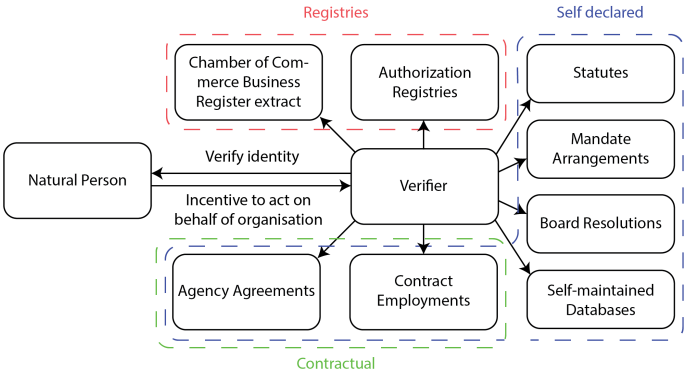

Fig. 2. Current situation of legal entity representation

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 [31]. 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 KVK, the system architecture is limited geographically to EU Member States because that is the boundary of the EBSI initiative and EDI. 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. Nonetheless, 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 EBSI and the coming EDI infrastructure.

IV. System Architecture

This section examines the system architecture of our decentralized peer-to-peer zero-trust architecture. The system architecture is intended to be an open standard for EU Member States and demonstrates the potential implications of the coming EDI and applications thereof.

In Figure 1, a visualization of the open standard system architecture in relation to the pillars of the CISA Zero Trust model 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. Retrieving the credential from EBSI directly is named a root credential, which gives full authorization over the legal entity. 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 is the irrefutable truth. Furthermore, all users may serve as a presenter to prove their authorization or act as a verifier to verify another user's credentials. Concerning adoption, it is up to the presenter to accept the verifier. Contrarily, it is up to the verifier to specify the accepted presentations from presenters. Each of the components in the system architecture of Figure 1 and accompanying terminology will be described in the following subsections.

A. Terminology

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 act on the principal's behalf, as specified in the PoA document. PoAs can be used for various 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 is described to have root PoA over that company. In the Netherlands, this is the functionary enlisted in the KVK Business Registry. Where an enlisted functionary is a user who has full authority over the legal entity.

Similar interpretations of PoAs exist, *e.g.* delegation, mandate, authorization, and guardianship [32, 33]. For several reasons, the term PoA is used in this work. Firstly, delegation is used ambiguously and may not have legal effect [34, 35]. Secondly, mandating has an alternative definition in public law[1] and moreover, the responsibility in our system should go with the attorney-in-fact, contrariwise to mandates. Thirdly, the term 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 [36], 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 sound 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 [37].

B. Trusted Issuers

In our zero-trust architecture, a trusted issuer is responsible for linking 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 a functionary and a legal entity is in most EU Member States recorded at a chamber of commerce, commercial court, or governmental agency [38]. These chambers, courts, and agencies are potential trusted issuers. Typically, trusted issuers only have a limited number of functionaries cataloged in their registry. For our architecture, this is not an issue as we provide a complete architecture for PoAs. The only condition which has to be held is that every legal entity has at least one functionary registered at a trusted issuer, this is always the case as otherwise, the legal entity would not exist.

C. European Blockchain Services Infrastructure

The EBSI 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 [39, 40]. The EBSI network is based on the Hyperledger Fabric platform and utilizes a permissioned consortium model [41] 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 functionaries of legal entities in the EBSI. These registrations will become available on the EBSI in the W3C verifiable credentials format [42], achievable through the Trusted Issuer Registry API of EBSI [43]. The verifiable credential is tailor-made and available in EBSI's Trusted Schemas Registry [44]. In case a registration of a functionary has to be revoked, this is made feasible by the Revocation and Endorsement Registry [45].

D. Users

As a user of our system, you are required to complete an onboarding process[2] 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 [47] and outlined in the eIDAS regulation [20, 48]. The feasibility of LoA high is a lively argument with respect to user's hardware concerns [49], privacy issues [50, 51], cross-border governmental distrust [52], and offline operability [53]. 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 we provided can still be operational with an already existing form of electronic identification, e.g. Ireland's MyGovID, Italy's SPID, France's FranceConnect, and the Netherlands' DigiD. However, this will make the system more centralized and dependable on these services, 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 [54, 55]. 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 root PoA of the legal entity they are a functionary 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. In this hierarchy, the user is in complete control over their PoAs and issued PoAs. Furthermore, the user is not required to trust another

[1] Article 10:10 Awb

[2] Specified as "enrolment" in the eIDAS regulation [46]

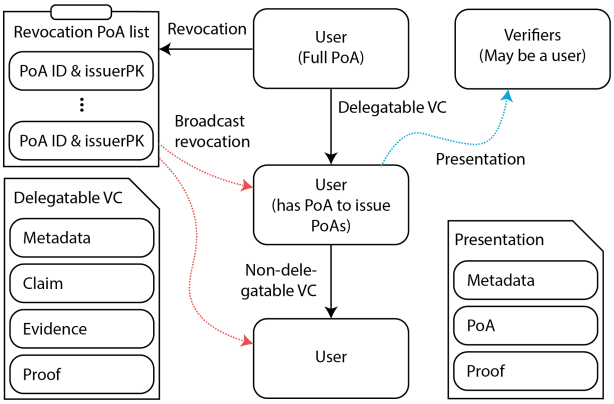

Fig. 3. Zero Trust Architecture for delegation

user, the user only needs to trust the trusted issuer. The system will contain branches and verifiable chains, which can be revoked or altered. Revocation is achieved by adding the ID of the PoA to the revocated PoA list. The list of revocations is gossiped through the network of users and verifiers. Conclusively, the user can 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

A verifier can verify the presentation presented by a user, and every user within the system can act as a verifier. However, a verifier can also be an entity outside the system that accepts presentations from our system. This is possible due to the format of a PoA, which is a delegatable verifiable credential according to the W3C standard [56]. Upon revocation of a delegatable verifiable credential, the credential ID, hash and issuer's public key are added to a list that is gossiped through the network. Due to the delegatable verifiable credential format and method of revocation, our zero-trust architecture system conjointly adheres to the Zero Knowledge Proof paradigm[3] [57]. Figure 3 provides a detailed overview of the components within our zero-trust architecture.

V. Design

We present the outcomes of implementing the zero-trust architecture for legal entities in an operational design. The design is built on top of TU Delft's Decentralized Web3 Societal Infrastructure [58], further called the IDknip. This Societal Infrastructure is a decentralized platform that is constructed to provide identity, trust, money, and data services. The IDknip has the functionality to onboard a user their identity which has been issued by a trusted issuer. Our design is built in Kotlin, therefore operates on Android OS. The network used is the internet over the IPv8 protocol, which allows for secure data sharing and communication among a network of peers [59]. In order to evaluate the performance and efficiency 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. Trusted Issuer - KVK

The implementation allows you to quickly and securely verify your identity using your legal identity. Consecutively, the user can obtain their PoA from the KVK. The requirement is that you are registered as a functionary at that legal entity. This is achieved through connecting with the HR Dataservice from the KVK. To receive a signed XML from which the functionaries of a legal entity can be deduced. In order to access this data, a fee for start-up costs of €1040 and €2.40 for each call is required[4] [60, 61]. 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 [62]. Once successful, the user can issue PoAs to other users. Figure 4 visualizes how a root PoA can be obtained from the KVK and then 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 KVK the option "Receive PoA from KVK" is chosen. Accordingly, the dialog of Figure 4c will show, where the user can fill in the KVK-number of which the user is a registered functionary in the Company Registry of the KVK of that legal entity. Once filled and 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 KVK data service. Accordingly, the KVK verifies if the provided legal entity indeed has a registered functionary matching the given name, surname, and birthday provided by the user identity. When a match is found, the user

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

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

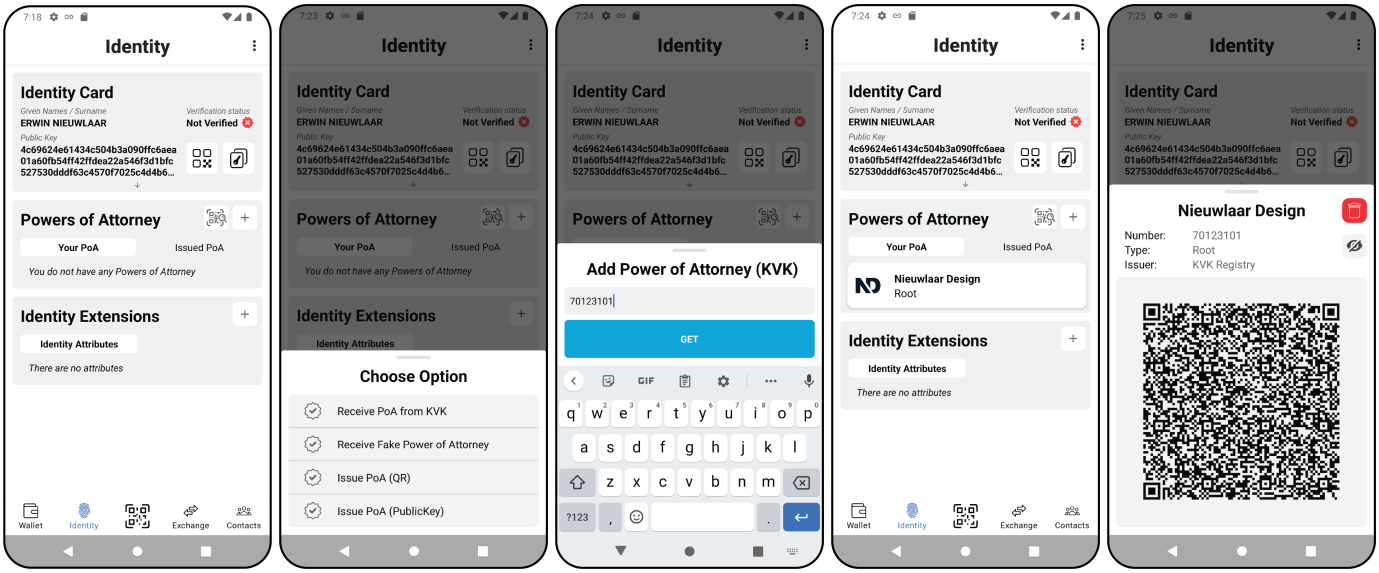

Fig. 4. Flow of obtaining Power of Attorney from the KVK. **(a)** Identity fragment of the IDknip application. **(b)** Add PoA menu. **(c)** Adding PoA dialog from the KVK. **(d)** Overview of the identity fragment with a root PoA obtained from the KVK. **(e)** The detailed dialog of the PoA with a verifiable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

will receive the PoA as 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 of revoking or delete the PoA, and a verifiable QR code.

B. European Blockchain Services Infrastructure

As shown in Figure 1, the Trusted Issuers are expected to put the credentials of owners or functionaries of a legal entity in the EBSI. Implementing the EBSI in a wallet is a burden as the logging frequently is incomprehensible. Additionally, figuring out an issue with the assistance of the service desk took several weeks. However, currently there exist a few wallets that are operational with the EBSI blockchain. Although, 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 design, 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 KVK's 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 functionary 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 be put in all the company functionaries. Accordingly, the user will be able to retrieve the PoA from EBSI by identifying themselves, making our architecture functional for all EU Member States.

Scheme 1. EBSI Power of Attorney Verifiable Credential

```
{
  <credential-metadata>,
  "credentialSubject": {
    "id": "did:ebsi:bef...k21",
    "powerOfAttorney": {
      "id": "did:ebsi:c27...9f1",
      "nameIssuer": "KVK",
      "idIssuer": "59581883",
      "type": "root",
      "nameLegalEntity": "Nieuwlaar Design",
      "idLegalEntityHolder": "70123101",
      "publicKeyHolder": "4c6..c60",
      "givenNamesHolder": "Erwin",
      "surnameHolder": "Nieuwlaar",
      "dateOfBirthHolder": "23-05-1994"
    },
    <powerOfAttorney-evidence>
  },
  <credential-proof>
}
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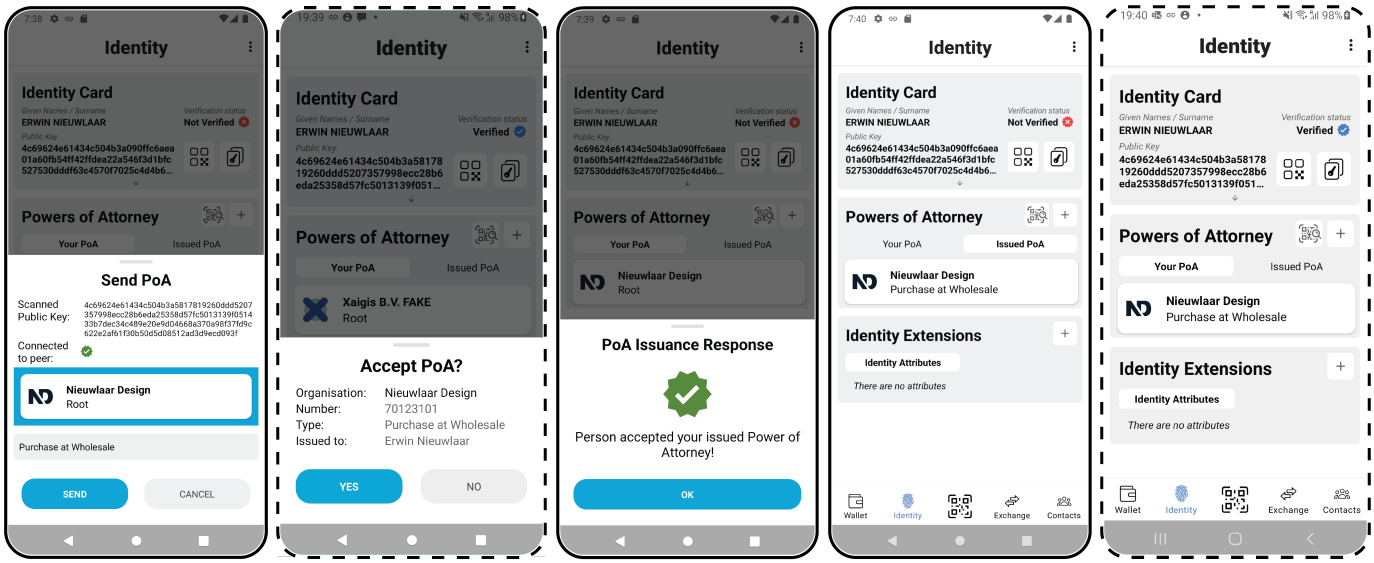

(a) Device 1 **(b)** Device 2 **(c)** Device 1 **(d)** Device 1 **(e)** Device 2

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.

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 according to the W3C standards and are therefore minimized for a clearer overview.

C. User

Once a user in a legal entity has obtained the PoA from the KVK, the user can 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 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 identity fragment in the issued PoA tab as presented in Figure 5d. Lastly, the attorney-in-fact now has the authorization to purchase at a business-only wholesale, as shown in Figure 5e. Within the application, any PoA can be created including the possibility to delegate PoAs.

D. Verifier - Makro

During a live demonstration at the Makro, the Makro functioned as the verifier. The Makro is a wholesale store in the Netherlands for business only *i.e.* only representatives of a legal entity are allowed to purchase at the Makro. The users enrolled as a functionary at the KVK obtained their PoA credentials. Consecutively, they could present the Makro that they are allowed to enter the Makro. Alternatively, the user that obtained the PoA credentials from the KVK could delegate another user a PoA. The user who has received the PoA can show a PoA presentation to the Makro. The Makro can verify the presentation and

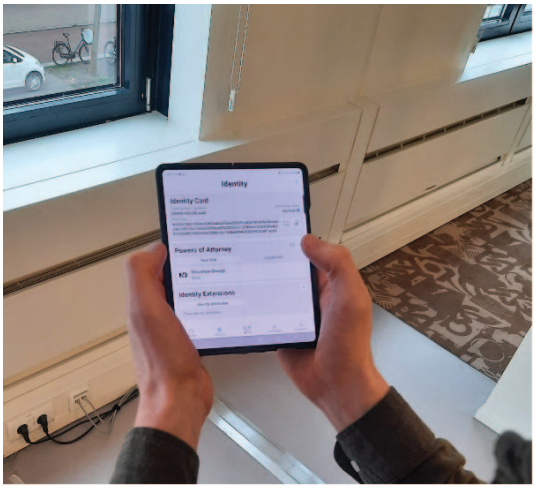

Fig. 6. Placeholder photo Makro demo (demo is komende week)

accordingly the user can enter and purchase at the wholesale.
A live demonstration at the Makro showed that our design was successfully implemented. The user was able to show their presentation to the Makro, where the Makro was able to verify the user's PoA respectively. The demonstration highlights the feasibility and practicality of implementing our zero-trust architecture for legal entities in a operational environment. Figure 6 shows a picture of the live demonstration at the headquarters of Makro.

VI. Performance Analysis

We will measure if our zero trust design is fit-for-purpose by analyzing the technical feasibility and the user experience. The technical feasibility is done by measuring CPU usage through various user stories and the user experience is measured by the time needed for the onboarding process and latencies of all user stories concerning PoAs. In light of the CPU usage, the processes of the IDknip have been recorded and visualized in Flame Charts [63, 64]. The process of obtaining a PoA from the KVK server was recorded using a Samsung Fold 3, which has a Snapdragon 888 CPU, and is shown in Figure 7. This user story was chosen for display as it appeared to be the most CPU-consuming process of all PoA user stories within the IDknip. For clarity purposes, the steps of the user story that has been recorded in Figure 7 are visualized in Figure 4. During the recording, the IPv8 protocol claimed a part of the CPU computational power by maintaining connectivity with all of Superapp's communities and new peer discoveries. 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 complete recording. Accordingly, we can conclude the load of the IDknip is small as through all its functionalities the CPU utilization is 35% at maximum. From Figure 7, we can observe that the process of obtaining a PoA from the KVK 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.

Furthermore, the latencies associated with onboarding a user's identity are displayed in Figure 8. The data shown in Figure 8 represent the identity onboarding of 7 novice users except for the data including the trained tag within their label. The data with the trained tag represents the latencies of 10 repeated measurements where the person knows all onboarding steps beforehand. Therefore, the trained person positioned the camera and NFC reading device more accurately, achieving a faster onboarding process and principally measuring the speed of the camera and NFC data transfer. From the figure, we can observe that the total time for a novice user to onboard their identity is high. The primary reason is the difficulty to understand how the passport should be scanned with NFC. This is caused by users not receiving a confirmation of their camera scan, and not understanding the image and text which explains the instructions for the NFC scan. An improved UX design for this step could solve this issue which would enable users to be able to onboard their identity within a minute.

Figure 9 displays the network latencies associated with various user stories, namely, 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 larger 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 also observe that the latencies are generally low for both WiFi and 4G connections, indicating that the system can handle requests on top of moderate network connectivity with similar efficiency.

VII. Conclusion

We presented a decentralized peer-to-peer zero-trust architecture for EU Member States and have shown it to be feasible to implement in a real-world use case. The architecture is proposed as an open standard, and we provide a reference open-source implementation to demonstrate its potential implications. The system architecture components are related to the pillars of the CISA Zero Trust model. 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

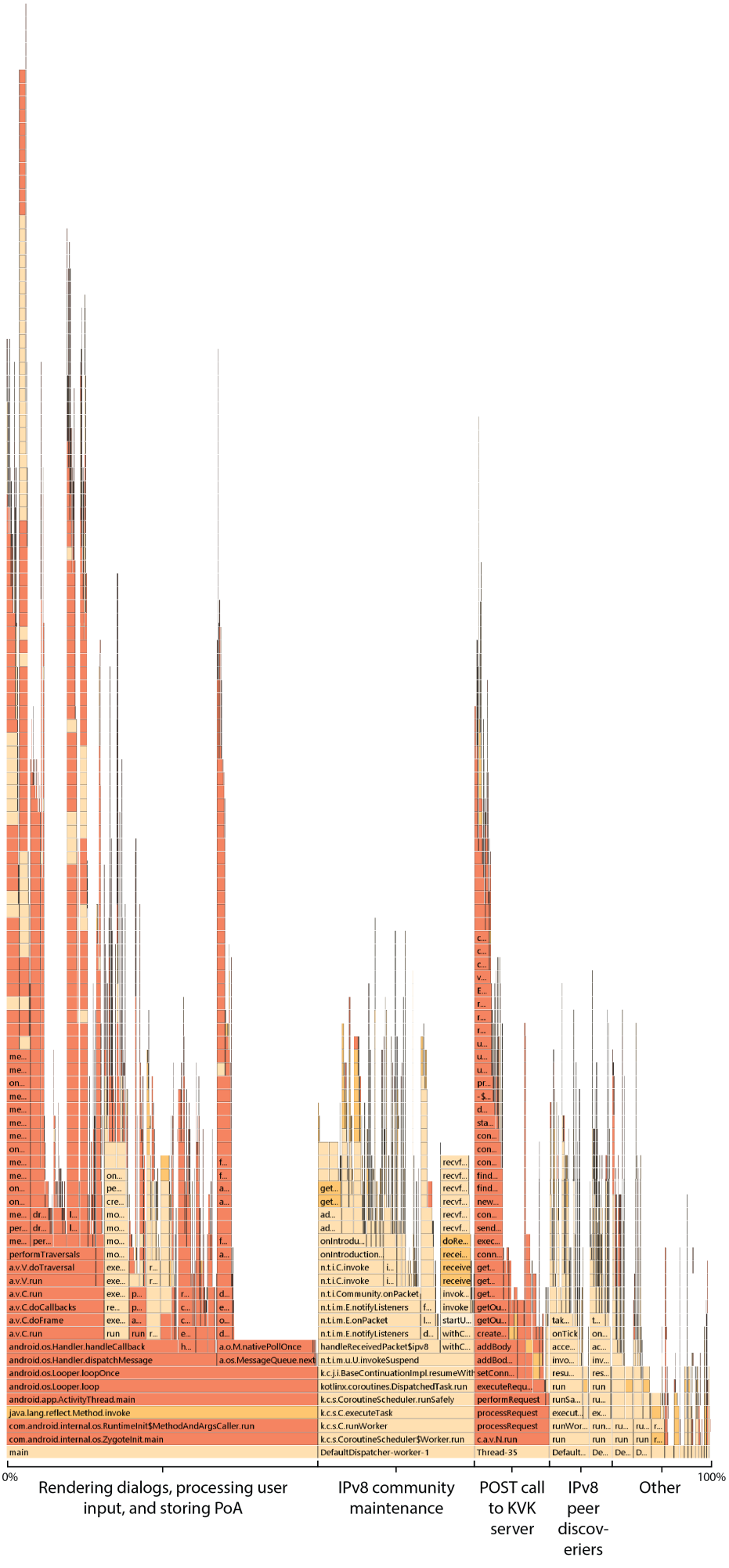

Fig. 7. Flame Chart of retrieving PoA from the KVK

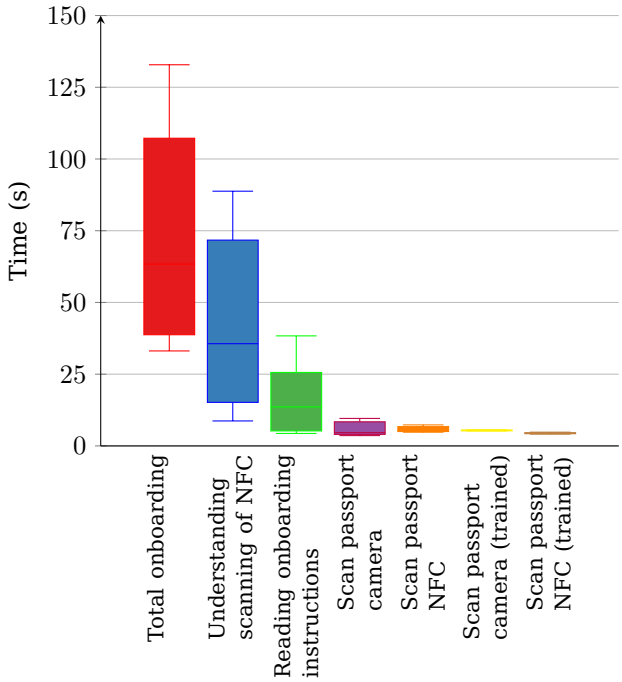

Fig. 8. Latencies onboarding identity

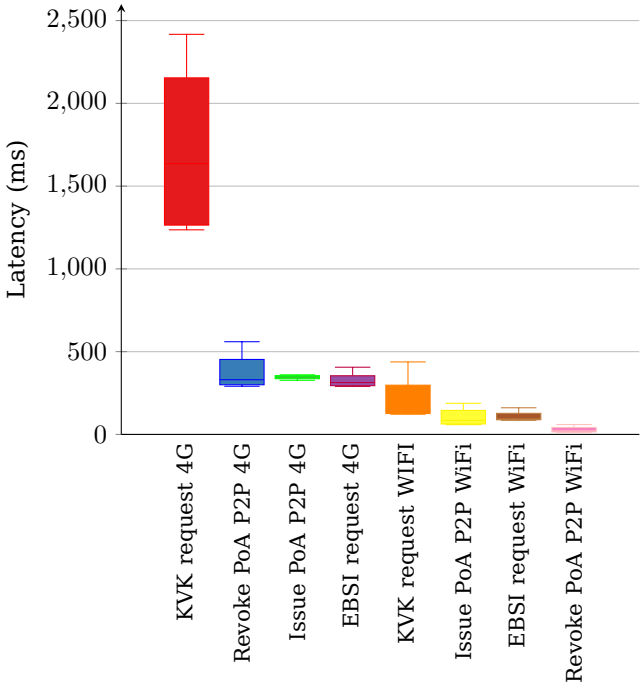

Fig. 9. Network latencies

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 prove 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 integration would enable secure and transparent cross-border transactions, digital identity verification, and trusted authorization among the European Member states. In conclusion from our performance analysis, 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 [49]. 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. Fifthly, 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. Sixthly, research can work on developing more information privacy in the light of delegatable Verifiable Credentials [56, 65]. 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 use the CISA Zero Trust Maturity Model for guidance on maturing our zero-trust architecture [25].

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