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Integrating Didcomm Messaging to ActivityPub-based Social Networks

by

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SNET
SERVICE-CENTRIC NETWORKING

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Berlin, August 9, 2022 Chuck Norris' son

Abstract

In this thesis, we show that lorem ipsum dolor sit amet.

Zusammenfassung

Hier kommt das deutsche Abstract hin. Wie das geht, kann man wie immer auf Wikipedia nachlesen `http://de.wikipedia.org/wiki/Abstract`...

Contents

1 Introduction

This section gives an introduction into the general field in which you are writing your thesis. It further describes the situation today, and the problems that are solved and not.

One of the most accepted and used definitions of OSN services was given by Boyd and Ellison in, who defined a Social Network Site as a web based service that allows individuals to

1.1 Motivation

Why choose this topic? Because identities are important. Web3 brings decentralization, and identities should stay behind. W3C provides us with new standards for interoperability, and we should take this goals in mind. [1]

1.2 Digital Identities

1.3 Identity Management

Identity management, sometimes called identity and access management, is composed of all the different ways to identify, authenticate and authorize someone to access systems or services within an organization or associated organizations.

There are several problems with our current identity management systems:

A paper-based identification such as a passport, birth certificate or driver's license is easy to lose, copy or be lost to theft. The bureaucracy behind this type of identity management is typically slow and hard to organize. The current identity and access management systems are storing your data on a centralized server along with everybody else's. This puts your digital property in danger as centralized systems are huge targets for hackers. Since 2019 alone, over 16 billion records have been leaked due to hacks and data breaches. This includes credit card numbers, addresses, phone numbers and other highly sensitive personal data. Current identities are not easily portable or verifiable. Blockchain identity management solves these issues.

1.4 Missing factors

It was this gap in technology that prevented digital currencies from being created or adopted in the past. Blockchain fills the gap for currencies, but it also fills the gap for decentralized identity systems, opening up a whole new world of possibilities for data ownership.

Your Blockchain-Based Digital Identity At least 1 billion people worldwide are unable to

claim ownership over their identities. This is one of the huge drawbacks of physical identity documentation. It's not widely available in every country. This leaves 1/7th of the entire planet unable to vote, open a bank account, or, in some cases, find a job.

Our current identity management systems are unfair and outdated, but there is a blockchain ID solution: a decentralized identity system that will revolutionize digital freedom. This is more critical now than ever before, with centralized companies left, right and center hoping to create the metaverse.

Your digital identity will be portable and verifiable all over the world, at any time of day. In addition, a blockchain-based decentralized identity is both private and secure. With verifiable credentials, your decentralized identity will empower you to interact with the SmartWeb without restrictions.

Your unique digital identity.

Imagine being able to verify your education qualifications or your date of birth without needing to actually show them. For example, a university degree could theoretically be on the blockchain and you could certify the credentials by checking the university or other issuing authority.

Similarly, you wouldn't have to show your physical ID to verify your date of birth. The authority that wants to know your age could instead use decentralized identifiers and verifiable credentials to find out if you're of the required age or not.

Authorization can be conducted in a trustless manner in which the digital identity in question is verified by an external source, and the person or organization checking can in turn verify the integrity of said source.

The verification of a proof is established by the verifier's judgment of the trustworthiness of the testimony.

This is known as a zero-knowledge proof.

Everyone in a distributed network has the same source of truth. This guarantees the authenticity of data without having to store it on the blockchain.

Blockchain technology has made it possible, for the first time ever, to have a trustlessly verifiable self-sovereign identity.

Blockchain Identity Management Blockchain identity solutions, such as Elastos DIDs, integrate state-of-the-art cryptography technology to ensure that your data is protected and private. By using decentralized identifiers, we can rebuild the structure of several flailing industries.

All of the following have poor identity management and could do with being brought up to date.

1.5 Problem statement

This section explains why this is important, why it is a problem, and why this hasn't been solved already yet. Centralized Identities, secure and open communication protocols. ActivityPub implementations at the present moment rely on HTTPS as their transport, which in turn relies on two centralized systems: DNS and SSL certificate authorities. Is there any way to

bring self-sovereignty to the federated social web? [2]

ActivityPub security concerns. Encryption, non-repudiation, confidentiality..... ? → No agreed-upon security mechanisms for ActivityPub. → No encryption in scope of ActivityPub. Research Questions What are the implications of introducing DIDs to Mastodon and ActivityPub in terms of usability, discovery and human-readability? Can a DID-compliant ActivityPub protocol use DIDComm for its standard communication? Can DIDs allow ActivityPub to stop relying on the DNS for its server-to-server discovery? Can DIDComm allow ActivityPub to stop relying on transport-level security for its communication?

1.6 Expected Outcome

The goal of this thesis is to have a fully functioning Mastodon instance that is DID-compliant and that implements ActivityPub using DIDComm as its communication protocol. Replacing the existing centralized identity management with a Self-Sovereign Identity approach through DIDs, and enabling a communication protocol that allows confidentiality, non-repudiation, authenticity, and integrity without being bound to a platform-specific security mechanism.

1.7 Outline

Overview of your thesis structure in this chapter.

2 Related Work

The following chapter covers the most important and significant concepts that are required to fully comprehend the approach of this thesis. This includes a closer look at decentralized communication protocols and identifier standards, as well as social networks that implement them. The revision and structuring of these concepts allows us to understand, build upon, and apply them in order to address our identified research questions.

2.1 ActivityPub

Present first activityStreams to then go ahead and explain how ActivityPub works:

In 2018, Mastodon started using ActivityPub. A decentralized social network protocol based upon the Activity Streams 2.0 data format, which provides a data model for representing an *"Activity"* using a JSON-based syntax [3]. ActivityStreams also provides a vocabulary that includes all the common terms you need to represent all the activities and content flowing around a social network. ActivityPub can be described as decentralized, because it provides two different APIs. The first one provides endpoints to connect clients to servers, and the second one, used in federated implementations, includes a server-to-server API [4]. After it was published as a Recommendation by the Social Web Working Group of the W3C in January 2018, Mastodon switched and pioneered the use of ActivityPub on a large scale. Promoting this way, its adoption.

2.1.1 Security and Privacy

Some text here...

2.2 Mastodon

In today's most popular social networks like Facebook, Twitter, or Youtube there exists a centralized architecture that keeps millions of users in one single platform. In which control, decision-making, user data, and censorship depend on a single profit-driven organization. On the contrary, Mastodon is a decentralized microblogging social network created with the idea of bringing social networking back into the hands of its users. In the time when switching apps, services every few years and having friends on a dozen different chat applications was a standard in terms of social networking, the German founder envisioned something that could put an end to this, and *last forever* [5]. Today, Mastodon is a network of more than 3,500 communities. Each operated by different individuals and organizations that implement their own policies, codes of conduct and discussion topics. By means of this, the user has the opportu-

nity to choose whichever instance he finds the most fitting. Mastodon takes a big share in the Fediverse. A single interoperable ecosystem of different social networks that can communicate with each other. In other words, it is a collection of federated social networks running on free open software on thousands of servers across the world, that implement the same protocol in order to be able to interact with each other. The Fediverse is developed by a community of people around the globe that is independent of any corporation or official institution. It is not profit-driven, and it gives you the freedom of choosing which service and instance of the Fediverse to register to. On top of that, you are free to run your own instance with your own policies and allow other users to join [6]. The range of services that can be found inside the Fediverse includes blogging, microblogging, video streaming, photo, music sharing as well as file hosting. Since its standardization, ActivityPub has been widely adopted in the Fediverse, being today the dominant protocol.

2.2.1 Well-known Endpoints

[7] As per documentation, Mastodon implements the following 4 different well-known endpoints:

2.2.1.1 Web Host Metadata

Web host metadata is lightweight metadata document format that allows for the identification of host policy or information, where "host" refers to the entity in charge of a collection of resources defined by URIs with a common URI host. It employs the XRD 1.0[1] document format, which offers a basic and flexible XML-based schema for resource description. Moreover, it provides two mechanisms for providing resource-specific information, specifically, link templates and *Link-based Resource Descriptor Documents* (LRDD). On the one hand, link templates require a URI in order to be a functioning link, thus avoiding the use of fixed URIs. On the other hand, the LRDD relation type is used to relate LRDD documents to resources or host-meta documents [8]. In the specific case of the Mastodon implementation, as shown in 2.2, accessing the host-meta endpoint will give us back the "lrdd" link to the Webfinger endpoint. In which specific resource information can be found.

```
1  GET /.well-known/host-meta HTTP/1.1
2  Host: mastodon.social
3  Accept: application/xrd+xml
```

Listing 2.1: Host Medata request

```
1  <?xml version="1.0" encoding="UTF-8"?>
2  <XRD xmlns="http://docs.oasis-open.org/ns/xri/xrd-1.0">
3  <Link rel="lrdd" template="https://mastodon.social/.well-known/webfinger?resource={uri}"/>
4  </XRD>
```

Listing 2.2: Host metadata response from mastodon.social

[1] https://docs.oasis-open.org/xri/xrd/v1.0/os/xrd-1.0-os.html

2.2.1.2 Webfinger

Finally, Webfinger is the protocol in which Mastodon heavily relies for the discovery process and for its normal functioning [9]. Webfinger allows for discovering information about persons or other entities on the Internet using HTTP that would not otherwise be useful as a locator, such as a personal profile address, identity service, telephone number or an email. Performing a query to a WebFinger endpoint requires a query component with a resource parameter, which is the URI that identifies the identity that is being looked up. Mastodon employs the *acct*[2] URI format, which aims to offer a scheme that generically identifies a user's account with a service provider without requiring a specific protocol to be used when interacting with the account. In the same way NodeInfo works, it returns a JRD Document describing the entity [10]. Fig. shows an example of the returned JRD that is being provided by the WebFinger endpoint in the mastodon social instance when querying the account "acct:bob@mastodon.social".

```
GET /.well-known/webfinger?resource=acct:bob@mastodon.social
Host: mastodon.social
Accept: application/xrd+xml
```

Listing 2.3: HTTP request to Webfinger endpoint

```
{
  "subject": "acct:bob@mastodon.social",
  "aliases": [
      "https://mastodon.social/@bob",
      "https://mastodon.social/users/bob"
  ],
  "links": [
      {
          "rel": "http://webfinger.net/rel/profile-page",
          "type": "text/html",
          "href": "https://mastodon.social/@bob"
      },
      {
          "rel": "self",
          "type": "application/activity+json",
          "href": "https://mastodon.social/users/bob"
      },
      {
          "rel": "http://ostatus.org/schema/1.0/subscribe",
          "template": "https://mastodon.social/authorize_interaction?uri={uri}"
      }
  ]
}
```

Listing 2.4: Webfinger response

[2] https://datatracker.ietf.org/doc/html/rfc7565

2.2.2 Security

2.2.2.1 HTTP Signature

2.2.2.2 JSON LD Signature

2.3 Decentralized Identifiers

Globally unique identifiers are used by individuals, organizations, abstract entities, and even internet of things devices for all kinds of different contexts. Nonetheless, the large majority of these globally unique identifiers are not under the entity's control. We rely on external authorities to issue them, allowing them to decide who or what they refer to and when they can be revoked. Their existence, validity scope and even the security mechanisms that protect them are all dependent on these external authorities. Leaving their actual owners helpless against any kind of threat or misuse [11]. In order to address this lack of control, the W3C DID Working Group conceptualized the Decentralized Identifiers or *DIDs*.

DIDs are a new type of globally unique identifier that enables individuals and organizations to create their own identifiers using trustworthy systems. By means of this, entities are able to prove control over them by authenticating using cryptographic proofs. Furthermore, given that the generation and assertion of DIDs are entity-controlled, an entity can create any number of DIDs that can be tailored and confined to specific contexts. This would enable interaction with other systems, institutions, or entities that require authentication while also limiting the amount of personal or private data to be revealed. All of this without the need to rely on a central authority [11]. To better illustrate how DIDs work, let's address the components which constitute DIDs. Figure 2.1 provides a basic overview of the major components of the Decentralized Identifier architecture.

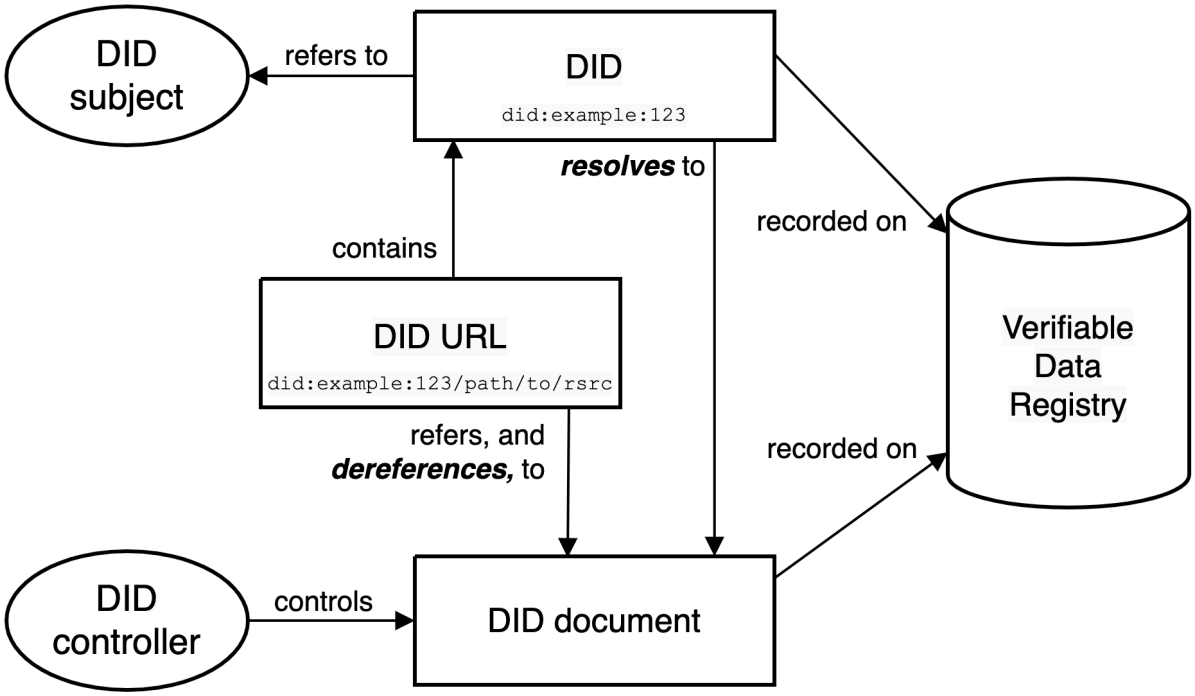

Figure 2.1: DID architecture overview [11]

2.3.1 DID

The DID itself is a URI[3] that consists of 3 different parts, namely the did URI scheme identifier, the method identifier and the DID method-specific identifier.

Figure 2.2: DID composition [11]

[3] https://www.rfc-editor.org/rfc/rfc3986

2.3.2 DID-URL

A DID can include path, query and fragment in order to be able to locate a specific resource inside a DID document, as shown in 2.1

2.3.3 DID-Subject

Refers to the entity being identified by the DID. According to the specification [11], any person, group, organization, physical thing, digital thing or logical thing can be a DID-Subject.

2.3.4 DID-Controller

The DID-controller is the entity that has the capability to make changes to the DID-Document. This entity is not necessarily the DID-Subject itself.

2.3.5 DID-Document

They contain information associated with a DID. They usually describe verification methods, such as cryptographic public keys, as well as services that are relevant to interactions with the DID-subject. An example of a DID Document can be seen in 2.5.

```
{
  "@context": "https://w3id.org/did/v1",
  "id": "did:example:123456789abcdefghi",
  "publicKey": [{
    "id": "did:example:123456789abcdefghi#keys-1",
    "type": "RsaVerificationKey2018",
    "owner": "did:example:123456789abcdefghi",
    "publicKeyPem": "..."
  }],
  "authentication": [{
    "type": "RsaSignatureAuthentication2018",
    "publicKey": "did:example:123456789abcdefghi#keys-1"
  }],
  "service": [{
    "type": "ExampleService",
    "serviceEndpoint": "https://example.com/endpoint/8377464"
  }]
}

%
```

Listing 2.5: Example DID-Document

The only required attribute for a DID-Document is the ID. Other optional attributes include a controller, which specifies the DID-controller; verification methods, used to authenticate or authorize interactions with the DID subject or associated parties; and services, which can be any type of service the DID subject wants to advertise, including decentralized identity management services for further discovery, authentication, authorization, or interaction.

2.3.6 DID-methods

DID-methods describe the processes for CRUD operations for DIDs and DID documents, based on a specific type of verifiable data registry. Each DID-method describe and implement their own security and privacy considerations. According to the DID registry of the W3C[4], there are around 130 registered DID-Methods. Based on their characteristics and patterns, the following a 4-way classification of DIDs has arised.

- **Ledger-based DIDs**: This includes all the DIDs that store DIDs in a blockchain or other Distributed Ledger Technologies (DLTs). Examples include did:btcr, did:ethr and did:trx, whose DIDs are stored correspondingly in the Bitcoin, Ethereum and Tron network [12].
- **Ledger Middleware ("Layer 2") DIDs**: Broadly speaking, Layer 2 refers to a framework or protocol that is built on top of an existing blockchain system that takes the transactional burden away from layer 1 and post finalized proofs back to layer 1. By removing this transaction load from layer 1, the base layer becomes less congested, and everything becomes more scalable [https://ethereum.org/en/layer-2/]. The Lightning Network (LN) is an example of a layer 2 Bitcoin protocol that offers users a fast micro-payment platform. Furthermore, regarding Layer 2 DID methods, the DIF has developed Sidetree[5]. A protocol for creating scalable blockchain-agnostic Decentralized Identifier networks that enables users to create globally unique, user-controlled identifiers and manage their associated PKI metadata, without the need for centralized authorities or trusted third parties [13]. Examples include: did:ion, did: elem.
- **Peer DIDs**: DIDs have the required ability to be resolvable, however not all of them have to be globally resolvable. The DIDs in this category do not exist on a global source of truth, but in a context of relationships between peers in a limited number of participants. Nonetheless, their validity is not affected due to the fact that they comply with the core properties and functionalities that a DID has to provide.
- **Static DIDs**: This type of DIDs are limited in the kind of operations that can be performed to them. These DIDs are not stored in any registry, consequently, it is not possible to update, deactivate or rotate them. Using the did:key method as an example, the DID-method-specific part of the DID is encoded in a way that the DID document can be deterministically extracted from the DID itself [14].

did:ethr: This DID-method was registered by Uport, an Ethereum-based system for self sovereign identity [15]. It allows any Ethereum smart contract or key pair account, or any secp256k1 public key to become a valid identifier [16]. UPort is a smart-contract-based system that abstracts user accounts using proxy contracts that are held by the user but may be retrieved if keys are lost. To do this, controller contracts create trusted entities for asserting ownership [17]

2.3.7 Verifiable Data Registry

Essentially, any system that enables capturing DIDs and returning required data to generate DID documents. This can be distributed ledgers, decentralized file systems, any type of

[4] https://www.w3.org/TR/did-spec-registries/#did-methods
[5] https://github.com/decentralized-identity/sidetree

database, peer-to-peer networks, or other types of trustworthy data storage [11].

2.3.8 DID resolver

A DID-resolver is able to implement the DID-resolution, which consists of taking a DID as an input, and giving a DID Document as an output [11]. As of the writing of this thesis, the Identifiers & Discovery Working Group (ID WG) has implemented a prototype Universal Resolver[6], which allows the resolution of DIDs for numerous DID-methods, including all the examples mentioned above. In addition, this working group has also developed a Universal Registrar[7], which allows the creation, edition and deactivation of the DIDs across different DID-methods.

2.4 DIDComm Messaging

2.4.1 Definition

The Hyperledger Foundation is an open-source collaborative effort intended to further develop blockchain technologies across industries [18]. Started in 2016 by the Linux Foundation, it has given birth to numerous enterprise-grade software open-source projects that can be classified into DLTs, libraries, tools and labs [19]. One of these graduated projects is Hyperledger Aries, which together with Hyperledger Indy (HI) and Hyperledger Ursa (HU), makes up the Sovereign Identity Blockchain Solutions of Hyperledger. HI supplies a distributed ledger specifically built for decentralized identity, HU is a shared cryptography library that helps to avoid duplicating cryptographic work across projects while also potentially increasing security. Finally, Aries provides solutions for SSI-based identity management, including key management, credential management, and an encrypted, peer-to-peer DID-based messaging system that is now labeled as Didcomm v1 [18]. Based on Didcomm v1, the Communication Working Group (CWG) of the DIF has implemented DIDcomm v2. Among other key differences between versions, such as formalizations of Didcomm v1 methods, Didcomm v2 has removed the special handling of Peer-DIDs in order to make all DIDs equal from the perspective of the DIDComm spec. Furthermore, the CWG pursues the standardization of DIDcomm not only to widen its implementation beyond Aries-based projects but to create an interoperable layer that would allow higher-order protocols to build upon its security, privacy, decentralization, and transport independence in the same way web services build upon HTTP. [20] [21]

From this point on, we are going to refer to DIDComm Messaging v2 only as DIDComm. Didcomm can be described as a communication protocol that promises a secure and private methodology that builds on top of the decentralized design of DIDs. Moreover, Didcomm is a very versatile protocol, as it supports a wide range of features, such as security, privacy, decentralization, routable, interoperability, and the ability to be transport-agnostic [21].

To better understand how it works, let's look at how it would work in a scenario where Alice wants to send a private message to Bob:

[6] https://github.com/decentralized-identity/universal-resolver
[7] https://uniregistrar.io/

Algorithm 1 Example of DID communication using DIDComm [22]

1: Alice has a private key sk_a and a DID Document for Bob containing an endpoint $(endpoint_{bob})$ and a public key (pk_b).
2: Bob has a private key sk_b and a DID Document for Alice containing her public key (pk_a).
3: Alice encrypts plaintext message (m) using pk_b and creates an encrypted message (eb).
4: Alice signs eb using her private key sk_a and creates a signature (s).
5: Alice sends (eb, s) to $endpoint_{bob}$.
6: Bob receives the message from Alice at $endpoint_{bob}$.
7: Bob verifies (s) using Alice's public key pk_a
8: **if** Verify $(eb, s, pk_a) = 1$ **then**
9: Bob decrypts eb using sk_b.
10: Bob reads the plaintext message (m) sent by Alice
11: **end if**

DIDComm differs from the current dominant web paradigm, where something as simple as an API call requires an almost immediate response through the same channel from the receiving end. This duplex request-response interaction is, however, not always possible as many agents may not have a constant network connection, or may interact only in larger time frames, or may even not listen over the same channel where the original message was sent. DIDComm's paradigm is asynchronous and simplex. Thus showing a bigger resemblance with the email paradigm. Furthermore, the web paradigm goes under the assumption that traditional methods for processes like authentication, session management, and end-to-end encryption are being used. Didcomm does not require certificates from external parties to establish trust, nor does it require constant connections for end-to-end transport-level encryption (TLS). Taking the security and privacy responsibility away from institutions and placing it with the agents. All of this without limiting the communication possibilities because of its ability to function as a base layer where opposed capabilities like sessions and synchronous interactions can be built upon. [21]

To achieve the encryption and signing processes mentioned in algorithm 1, Didcomm implements a family of the Internet Engineering Task Force (IETF) standards, collectively called JSON Object Signing and Encryption (JOSE), which will be further explained in the next section.

2.4.2 JOSE Family

This RFC family includes both the Json Web Signature (JWS) and the Json Web Encryption (JWE) standards that are subclasses of the Json Web Token (JWT), and Json Web Key (JWK).

Compare with other encryption methods. (TLS, Whatsapp end-to-end, Signal) (Use image below)

3 Concept and Design

The standards presented in Chapter 2 show the potential improvements that can be achieved in key components of ActiviyPub-based social networks such as identity management, discovery, and communication. In this section, we are going to go through the different steps that are required firstly to integrate DIDs into an ActivityPub-based social network, and finally to enable DIDComm Messaging v2 for its communication.

The outline for this chapter is the following. First, individual concepts and definitions of the ActivityPub implementation are introduced and described. Then, an example of a simple use-case in a contemporary ActivityPub server is going to be illustrated and analyzed in order to be able to compare it with section 4.5, which presents the same use-case but with the proposed concept and design that includes DID integration and DIDComm enablement. Consequently, the reasons behind every decision made are going to be detailed in section 4.6, along with comparisons with other non-formalized proposals.

As explained in Chapter 2, Mastodon is the social network that pioneered the use of ActivityPub on a large scale, and it is also the social network with the most active users and presence inside the Fediverse. For this reason, the ideas presented in this section and the modus operandi of the ActivityPub server are going to be scoped to the actual implementation in Mastodon.

3.1 Definitions

Mastodon has implemented its own ActivityPub server, and with it also its own terms to express different social network vocabulary. In order to prevent confusion or ambiguities, the used terms in this chapter are explained here.

- **Username**: The username in Mastodon consists of a unique local username and the domain of the instance. Ex. alice@example.com
- **Actor object**: In this section, the term Actor object refers solely to the ActivityPub's actor object explained in Chapter 2.
- **Toot**: In the user-facing part of Mastodon, a Toot is the äquivalent of a Tweet in Twitter. This is a small status update with a 500 character limit.
- **Status**: In the backend of Mastodon, the descriptor used for a Toot is a Status. Moreover, an account in Mastodon has a 1:n relationship with status.

3.2 Use case

In order to explain the current ActivityPub flow in Mastodon, let's describe what happens in the simple use case:

Alice has an account in the Mastodon instance mastodon.social and follows Bob, who has an account in the Mastodon instance mastodontech.de. Alice sends a direct message to Bob with the text: "Hello Bob!"

3.3 Today's implementation

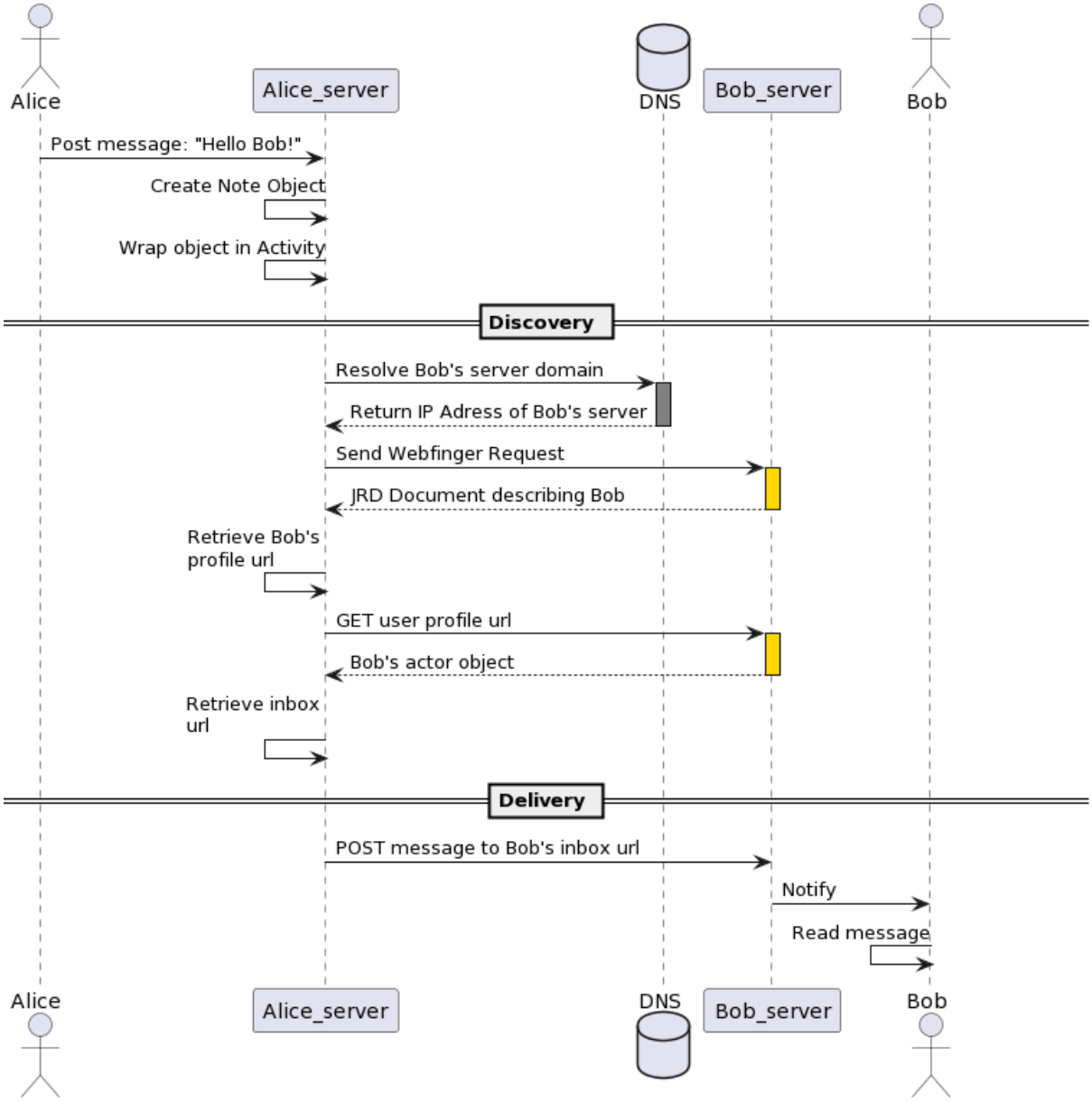

Figure 3.1: Current flow for sending message

3.3.1 Object creation

The first thing that happens when Alice presses the send button is the creation of an ActivityStreams object. In this case, the object is of type *Note*, and will be created by the ActivityPub server inside the Mastodon instance, as shown in 3.2. Then, following the ActivityPub pattern of *some activity by some actor being taken on some object*, the server wraps it in an ActivityStreams *Create* activity, which contains Alice as the actor. This is illustrated by 3.3. Now that the actor, the activity, and the object are well defined and wrapped, it is time to shift our focus to the recipients of this note object. The ActivityPub server will now look at all the fields of the ActivityStreams *Audience*, which includes: to, bto, cc, bcc, and audience [3], where all the addresses of the recipients can be retrieved. Afterwards, depending on where the recipient's account lives, the ActivityPub server may take one of two options. Even though the use-case explicitly dictates that Bob's account resides in a different Mastodon instance, both cases will still be explained.

```
{
  "a":  1,
  "b":  "2",
  "c":  true
}
```

Listing 3.1: JSON example

```
  {
    "@context": "https://www.w3.org/ns/activitystreams",
    "type": "Note",
    "to": "http://bob_server.com/users/bob",
    "attributedTo": "http://alice_server.com/users/alice",
    "content": "Hello Bob!"
  }
```

Listing 3.2: ActivityStreams note object

```
  {
    "@context": "https://www.w3.org/ns/activitystreams",
    "type": "Create",
    "id": "https://alice_server/users/alice/statuses/634367/activity",
    "to": "http://bob_server.com/users/bob",
    "actor": "http://alice_server.com/users/alice",
    "object": {
      "type": "Note",
      "to": "http://bob_server.com/users/bob",
      "attributedTo": "http://alice_server.com/users/alice",
      "content": "Hello Bob!"
    }
  }
```

Listing 3.3: ActivityStreams create activity

3.3.2 Same-server delivery

If the recipient's account is on the same server, there is then no explicit discovery process. A simple query in the ActivityPub's server would find the right account and save the status within the account's statuses.

3.3.3 Discovery

On the contrary, when the recipient's account is not in the same server, then a discovery process must be started. Discovery is the fundamental part of the federated side of Mastodon. Without it, users within different instances would not be able to interact, as the instance itself does not know where to find the actor object with all required endpoints to send or receive activities from and to external accounts. For this reason, the current way to look up for other accounts is through the DNS. In the same way Email works, the domain part of the username in Mastodon points to the domain of the instance where the account lives. The purpose of the discovery in this specific use-case is to find the inbox url of Bob, which can can be found in Bob's actor object. As explained in chapter 2, Mastodon includes a series of well-known endpoints that are used to retrieve information about the host itself, as well as resources or entities that are managed under the same host.By default, when the account is not found on the same server, a Webfinger query is performed. In our case, Bob's account lives inside *bob_server.com*. The request shown in 3.4 will return a JRD Document, as shown in fig. 3.5. Based on this document, the Mastodon instance retrieves the link with the *rel: 'self'* which includes the type and the href where the Bob's actor object can be retrieved. If the Webfinger request returns a 404 code, it will then try, as a fallback, using the Host-Meta endpoint. The request and response are displayed in 3.6 3.7. If successful, it will then proceed to take the link template provided and try the Webfinger request once more before throwing an error. After retrieving the needed URL, a subsequent HTTP GET request to this endpoint with the specific *application/activity+json* header will resolve Bob's actor object.

```
GET /.well-known/webfinger?resource=acct:bob@bob_server.com HTTP/1.1
Host: bob_server.com
Accept: application/ld+json
```

Listing 3.4: Webfinger request

```
{
  "subject": "acct:bob@bob_server.com",
  "aliases": [
    "https://bob_server.com/@bob",
    "https://bob_server.com/users/bob"
  ],
  "links": [{
      "rel": "http://webfinger.net/rel/profile-page",
      "type": "text/html",
      "href": "https://bob_server.com/@bob"
    },
    {
      "rel": "self",
      "type": "application/activity+json",
      "href": "https://bob_server.com/users/bob"
    },
    {
      "rel": "http://ostatus.org/schema/1.0/subscribe",
      "template": "https://bob_server.com/authorize_interaction?uri={uri}"
    }
  ]
}
```

Listing 3.5: JRD Document

```
GET /.well-known/host-meta HTTP/1.1
Host: bob_server.com
Accept: application/xrd+xml
```

Listing 3.6: Hostmeta request

```
<?xml version="1.0" encoding="UTF-8"?>
<XRD xmlns="http://docs.oasis-open.org/ns/xri/xrd-1.0">
    <Link rel="lrdd" template="https://bob_server.com/.well-known/webfinger?resource={uri}"
  />
</XRD>
```

Listing 3.7: Hostmeta response

3.3.4 Delivery

Succeeding the retrieval of Bob's actor object and therefore the needed inbox URL, a delivery can now take place. In this case, an HTTP POST request with the previously generated activity object. In order to provide end-to-end message integrity and to authenticate Alice in Bob's server, the request is signed by Alice's ActivityPub server using the HTTP Signature specification. Finally, upon receiving the POST request to Bob's inbox URL, Bob's server verifies the validity of the signature using Alice's public key. After a successful validation, it saves the Note object in Bob's statuses.

As indicated in chapter 2, HTTP signatures are not part of the ActivityPub protocol standard. These integrity and authentication features are within the Mastodon implementation of an ActivityPub server.

3.4 Proposed implementation

Proposed implementation Having seen the current flow of our use case mentioned above in a working ActivityPub-based social network, this section will now address the first research question of this bachelor thesis. That is, the implications of integrating DIDs to a Mastodon instance, and therefore to ActivityPub.

3.4.1 Implications of integrating DIDs

As mentioned in the definitions section, Mastodon's full username includes the domain of the server, and a locally-unique username. This type of username accomplishes the goals of human-readability and uniqueness. In addition, they are resolvable using DNS and the discovery methods previously mentioned in section chapter 2. An ActivityPub actor object using such a username is shown in 3.8.

The first question that needs to be addressed when approaching the integration of DIDs to Mastodon and therefore ActivityPub is, what are the implications of switching from standard mastodon usernames to DIDs. Integrating DID to ActivityPub points immediately to the actor's object. Making the switch would mean that the DID has to be included. Currently, most of the interactions of the ActivityPub server inside Mastodon require the ID attribute to resolve to

```
{
  "@context": [
      "https://www.w3.org/ns/activitystreams",
      "https://w3id.org/security/v1",
  ],
  "id": "http://alice_server.com/users/alice",
  "type": "Person",
  "following": "http://alice_server.com/users/alice/following",
  "followers": "http://alice_server.com/users/alice/followers",
  "inbox": "http://alice_server.com/users/alice/inbox",
  "outbox": "http://alice_server.com/users/alice/outbox",
  "featured": "http://alice_server.com/users/alice/collections/featured",
  "featuredTags": "http://alice_server.com/users/alice/collections/tags",
  "preferredUsername": "alice",
  "name": "",
  "summary": "",
  "url": "http://alice_server.com/@alice",
  "manuallyApprovesFollowers": false,
  "discoverable": false,
  "published": "2022-06-14T00:00:00Z",
}
```

Listing 3.8: Alice's actor object

the Actor's profile and thus the Actor's object. Following a simple strategie, we could simply replace the username with the DID. Thus having an ID attribute that may look like this:

DID URLs provide a lot of freedom of usability for DIDs. In addition to the ID, the actor's object must provide a supplementary set of URLs that point to different collections related to the Actor. These include mandatory attributes, like the outbox and the inbox, and other optional attributes such as the followers and following attributes. What if, instead of using the actual URL of these collections, we specify DID URLs that then point to the correct endpoint inside the DID-Document. This example is illustrated in fig. (Activitypub actor with all DID URLS).

4 Implementation

Describe the details of the actual implementation here...

5 Evaluation

The evaluation of the thesis should be described in this chapter

6 Conclusion

Describe what you did here

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Bibliography

[1] Guttenberg, "Double Brackets WiLL preserve cApItAlIzAtIoN," *Guttenberg Press*, 2011. [Online]. Available: http://www.examplelink.de

[2] C. Webber and M. Sporny, "Activitypub: From decentralized to distributed social networks," Dec 2017. [Online]. Available: https://github.com/WebOfTrustInfo/rwot5-boston/blob/fcbc33835c1b76b7526a8a82cd9cac9c23828711/final-documents/activitypub-decentralized-distributed.pdf

[3] "Activity streams 2.0," May 2017. [Online]. Available: https://www.w3.org/TR/activitystreams-core/

[4] C. Lemmer-Webber, J. Tallon, A. Guy, and E. Prodromou, "1.1 social web working group," Jan 2018. [Online]. Available: https://www.w3.org/TR/activitypub

[5] S. Tilley, "One mammoth of a job: An interview with eugen rochko of mastodon," Jul 2018. [Online]. Available: https://medium.com/we-distribute/one-mammoth-of-a-job-an-interview-with-eugen-rochko-of-mastodon-23b159d6796a

[6] J. Holloway, "What on earth is the fediverse and why does it matter?" Oct 2018. [Online]. Available: https://newatlas.com/what-is-the-fediverse/56385/

[7] M. Nottingham, "Rfc 8615 - well-known uniform resource identifiers (uris)," May 2019. [Online]. Available: https://datatracker.ietf.org/doc/html/rfc8615

[8] B. Cook, "Rfc 6415 - web host metadata," Oct 2011. [Online]. Available: https://datatracker.ietf.org/doc/html/rfc6415

[9] E. Rochko, "Webfinger," Jan 2020. [Online]. Available: https://docs.joinmastodon.org/spec/webfinger/

[10] P. Jones, G. Salgueiro, M. Jones, and J. Smarr, "Rfc 7033 - webfinger," Sep 2013. [Online]. Available: https://datatracker.ietf.org/doc/html/rfc7033

[11] M. Sporny, D. Longley, M. Sabadello, D. Reed, and O. Steele, "Decentralized identifiers (dids) v1.0," Aug 2021. [Online]. Available: https://www.w3.org/TR/did-core/

[12] A. Preukschat and D. Reed, *Self-sovereign identity decentralized digital identity and verifiable credentials*. O'REILLY MEDIA, 2021.

[13] D. Buchner, O. Steele, and T. Ronda, "Sidetree v1.0.0," Jan 2021. [Online]. Available: https://identity.foundation/sidetree/spec/

[14] D. Longley, D. Zagidulin, and M. Sporny, "The did:key method v0.7," May 2022. [Online]. Available: https://w3c-ccg.github.io/did-method-key/

[15] D. C. Lundkvist, R. Heck, J. Torstensson, Z. Mitton, and M. Sena, "Uport: A platform for self-sovereign identity," p. 16, 2016.

[16] M. Nistor, P. Grassberger, and Z. Carlin, "Ethr did method specification," Jun 2022. [Online]. Available: https://github.com/decentralized-identity/ethr-did-resolver/blob/master/doc/did-method-spec.md

[17] M. Westerkamp, S. Göndör, and A. Küpper, "Tawki: Towards self-sovereign social communication," in *2019 IEEE International Conference on Decentralized Applications and Infrastructures (DAPPCON)*, 2019, pp. 29–38.

[18] R. Jones and D. Boswell, "Hyperledger - hyperledger," Jul 2022. [Online]. Available: https://wiki.hyperledger.org/

[19] A. Lusard, A. Le Hors, B. Muscara, D. Boswell, and C. Zsigri, "An overview of hyperledger foundation," Oct 2021. [Online]. Available: https://www.hyperledger.org/wp-content/uploads/2021/11/HL_Paper_HyperledgerOverview_102721.pdf

[20] K. Young, "Understanding didcomm," Sep 2020. [Online]. Available: https://medium.com/decentralized-identity/understanding-didcomm-14da547ca36b

[21] "Didcomm messaging," May 2020. [Online]. Available: https://identity.foundation/didcomm-messaging/spec

[22] W. Abramson, A. J. Hall, P. Papadopoulos, N. Pitropakis, and W. J. Buchanan, "A distributed trust framework for privacy-preserving machine learning," in *Trust, Privacy and Security in Digital Business*. Springer International Publishing, 2020, pp. 205–220. [Online]. Available: https://doi.org/10.1007%2F978-3-030-58986-8_14

Appendices

Appendix 1

```
for($i=1; $i<123; $i++)
{
    echo "work harder! ;)";
}
```