Enabling Decentralised Identifiers and Verifiable Credentials for Constrained Internet-of-Things Devices using OAuth-based Delegation

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Motivation: Identifiers and IoT

- It should be possible to use services and devices while preserving privacy and preventing tracking
- Current identifier and certificate solutions have several problems
  - Different identifier for each service, lack of interoperability
  - Social logins: lack of privacy and control by the user
  - Very complicated to provide privacy-preserving proofs online
- From privacy's point of view, digital identifiers should provide:
  - Self-sovereignty (owner controls the identifier)
  - Ability to change identifiers at will
  - Anonymity
Use Case: Printing at University

University

Trusted service

Right to manage access control for my printers

Printing Service (PS)

Printing Service and its devices

Pre-shared key for token generation

Printer (IoT device)

User

DID

Access token + document to print

Process printing request

Authorisation Server (AS)
Requirements of Use Case

- User (visiting lecturer) wants to print a document before the lecture in a secure way
  - User does not have a university user account
  - Printers are managed by a third-party printing service, which collaborates with the university

- User should stay anonymous as much as possible
  - Printing Service (PS), Authorisation Server (AS), or Printer will never learn user's real identity or able to track user

- User and printing service need mutually authenticate each other:
  - Printing Service is trusted by University
  - Authorisation Server is trusted by Printing Service
  - User has right to print from University
Decentralised Identifiers and Verifiable Credentials

- Decentralised Identifiers (DIDs) aim to provide *self-sovereignty*
  - DIDs can be created by the user without dependence on any third party, hence a large number of DIDs can be used (even different one for each transaction)
  - Often derived from key pair, e.g.: `did:sov:3k9dg356wdcj5gf2k9bw8kfg7a`

- With *verifiable credentials* (VCs), owner of identifier can “prove” something (e.g. date of birth, degree) about themselves
  - Selective disclosure: disclose only part of the information present in credential
  - Zero-knowledge Proofs (ZKP) allow one to prove of, e.g., being over certain age without revealing real age

- IoT devices may not be able to use public-key cryptography (resource constrains, lack of entropy, cost of upgrading, etc.)

- **How to use privacy-enabling properties of DIDs and VCs with existing constrained IoT devices?**
Existing Solutions for IoT Authentication and Authorisation

• OAuth 2.0 allows a client to obtain access to protected resource, residing on resource server (RS)
  – Access control is managed by authorisation server (AS), which issues access tokens
  – OAuth does not define used authentication solution
  – ACE extension for constrained IoT devices: allows usage of proof-of-possession tokens that are based on pre-shared key

• Some technologies are not relevant for this use case
  – OpenID Connect: functionality is provided by DIDs and VCs
  – User Managed Access (UMA) 2.0: not always suitable for constrained devices
Delegating DID processing with OAuth

- Authorisation Server (AS) can act as a bridge between OAuth and DIDs
  - All actors except the device (printer) utilize DIDs and VCs for mutual authentication
  - Printer delegates DID processing to AS
- AS issues proof-of-possession access tokens to client (Lecturer), after authentication has been performed (ACE-OAuth)
  - Lecturer uses the access token to access the printer
Printing at University: Actors

- **University**: Represents the printing infrastructure at the university.
- **User**: The individual who needs to print documents.
- **DID**: The DID (Decentralized Identifier) of the user.
- **Authorisation Server (AS)**: Handles the authorization process.
- **Printing Service (PS)**: Manages access control for printers.
- **Printer (IoT device)**: The physical printer that prints the documents.

**Key Processes**:
- **Right to print**: The user has the right to use the printing service.
- **Process printing request**: The user requests to print a document.
- **Access token + document to print**: The user provides an access token and the document to print.
- **Right to manage access control for my printers**: The user can control access to their printers.
- **Pre-shared key for token generation**: A key used to generate access tokens.

**Connections**:
- The user connects to the Authorisation Server (AS) to process the printing request.
- The AS forwards the request to the Printing Service (PS).
- The PS manages access control and generates access tokens.
- The user uses the access token to print the document on the printer.

**Trust Model**:
- The system includes a trusted service to ensure secure communication and access control.
Message Flow

1. Service discovery
2. Authorisation request for "Printer" using ACE-OAuth
3. P(PS trusted by University), P(AS authorised by PS), request for user's right to print
4. P(Right to print from University)
5. Proof-of-possession access token
6. Proof-of-possession access token
Implementation

- The described solution has been implemented using Sovrin DID scheme (Hyperledger Indy) and OAuth2 server
  - User receives credentials from a Hyperledger Indy instance
  - User contacts OAuth server as usual
  - OAuth server generates a proof request containing a nonce
  - User generates a proof based on credentials using the nonce
  - Communication continues using standard OAuth protocol

- The source code will be made available before the publication of the paper
Comparison with Existing Solutions

- Using decentralised identifiers improves privacy

<table>
<thead>
<tr>
<th></th>
<th>X.509 Certificates</th>
<th>DID + VC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granularity</td>
<td>Coarse</td>
<td>Fine-grained</td>
</tr>
<tr>
<td>Duration</td>
<td>Usually long</td>
<td>Short or long</td>
</tr>
<tr>
<td>Processing</td>
<td>By humans</td>
<td>Machine-readable</td>
</tr>
</tbody>
</table>

- Printing service or the printer will never learn real identify of user
  - User can change DIDs frequently to protect against correlations attacks

- Proposed solution is compatible with and complementary to OAuth and its extensions
  - Provides mutual authentication, decouples resource server from AS, can provide trusted AS discovery
  - No modification to the actual device (printer) necessary
Conclusions

• Decentralised identifiers and verifiable credentials improve privacy in several situations
  – Open standards, allowing easy deployment and adoption across organisations and industries

• Delegation allows constrained OAuth-capable devices to take advantage of DIDs and VCs
  – Without any modifications to existing devices

• We have implemented a proof-of-concept solution which will be released as open source

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Backup slide: Message Flow

• User and printing service mutually authenticate each other using proofs:
  – Printing Service is trusted by University
  – Authorisation Server is trusted by Printing Service
  – User has right to print from University

• Afterwards, proof-of-possession access token, derived from pre-shared key, is issued using standard ACE-Oauth

• Message flow can be optimised by transmitting proofs during TLS handshake, utilising Encrypted Server Name Indication extension (TLS 1.3)
Verifiable Credential Example

{
  "@context": [
    "https://www.w3.org/2018/credentials/v1",
    "https://example.com/examples/v1"
  ],
  "id": "http://example.gov/credentials/3732",
  "type": ["VerifiableCredential", "UniversityDegreeCredential"],
  "issuer": "https://example.edu",
  "issuanceDate": "2010-01-01",
  "credentialSubject": {
    "id": "did:example:ebfeb1f712ebc6f1c276e12ec21",
    "degree": {
      "type": "BachelorDegree",
      "name": "Bachelor of Science in Mechanical Engineering"
    }
  },
  "proof": {
    "type": "RsaSignature2018",
    "created": "2018-06-18T21:19:10Z",
    "verificationMethod": "https://example.com/jdoe/keys/1",
    "nonce": "c0ae1c8e-c7e7-469f-b252-86e6a0e7387e",
    "signatureValue": "BavEll0/I1zpYw8XNii1bgVg/sCneO4Jugez8RwDg/+MCRVpjOboDoe4SxxKjkCOvKiCHGDvc4krqi6Z1n0UfqzxGfmtCuFibcC1wpsPRdW+gGsutPTLzvueMWmFhwYmflFpbBu95t501+rSLHIEuujM/+PXr9Cky6Ed+W3JT24="
  }
}
ACE-OAuth Token Response

Header: Created (Code=2.01)
Content-Format: "application/ace+cbor"

Payload:

```
{
  "access_token" : b64'SlAV32hkKG ...
  (remainder of CWT omitted for brevity;
  CWT contains COSE_Key in the "cnf" claim),
  "profile" : "coap_dtls",
  "expires_in" : "3600",
  "cnf" : {
    "COSE_Key" : {
      "kty" : "Symmetric",
      "kid" : b64'39Gqlw',
      "k" : b64'hJtXhkV8FJG+Onbc6mxCcQh'
    }
  }
}
```
Backup slide: Implementation

• Used software
  – https://github.com/hyperledger/indy-sdk/
  – https://github.com/bshaffer/oauth2-server-php

• Proofs are processed in JSON using Base64 encoding

• Implementation is written using Python, other bindings are also available for Indy SDK