MULTIDARKROOM

ZERO KNOWLEDGE MULTI PARTY SIGNATURES WITH APPLICATION TO DISTRIBUTED LEDGERS

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ABSTRACT

Multidarkroom is a novel signature scheme supporting unlinkable signatures by multiple parties authenticated by means of a zero-knowledge credential scheme. Multidarkroom integrates with blockchains to ensure condidentiality, authenticity and availability even when credential issuing authorities are offline. We implement and evaluate a Multidarkroom smart contract for Zenroom and present an application related to multiple anonymous signatures by authenticated parties. Multidarkroom uses short and computationally efficient signatures and credentials whose verification takes the longest time to compute.

I Introduction

Multi-party computation [] applied to the signing process [] allows the issuance of signatures without requiring any of the participating parties to disclose secret signing keys to each other, nor requires the presence of a trusted third-party to receive them and compose the signatures. However, established schemes have shortcomings. Some do not provide the necessary efficiency, re-randomization, or blind issuance properties necessary to implement the privacy preserving features necessary for the application to trustless distributed systems. Other schemes are prone to rogue-key attacks [Boneh et al., 2020] in the absence of authentication methods to grant that signatures are produced by legitimate key holders.

The lack of efficient and privacy-preserving signature schemes impacts distributed ledger platforms that support 'smart contracts' as well distributed computing architectures where trust is not shared among participants, but granted by one or more authorities through credential issuance for the generation of non-interactive and unlinkable proofs.

Multidarkroom uses short and computationally efficient signatures composed of exactly two group elements that are linked to each other. The size of the signature remains constant regardless of the number of parties that are signing, while the credential size grows linearly. Furthermure, after a one-time setup phase where the users collect and aggregate a threshold number of verification keys from the autorities, the attribute showing and verification O(1) in terms of both cryptographic computations and communication of cryptographic material, irrespective of the number of authorities.

Our evaluationof the Multiparty primities shows very promising results. Verifiction takes about 10ms, while signing a document is about 3 times faster.

Contributions: This paper makes three key contributions:

- We describe the signature scheme underlying Multidarkroom, including how key generation, signing and verification operate (Section II). The scheme is an application of the BLS signature scheme [Boneh et al., 2018] fitted with features to grant the unlinkability of signatures and to secure it against rogue-key attacks.
- We describe the credential scheme underlying Multidarkroom, including how key generation, issuance, aggregation and verification of credentials operate (Section III). The scheme is an application of the Coconut credential scheme [Sonnino et al., 2018] that is general purpose and can be scaled to a fully distributed threshold issuance that is re-randomizable.

- We implement a Zencode scenario of Multidarkroom to be executed on and off-chain by the Zenroom VM, complete with functions for public credential issuance, signature session creation and multi-party non-interactive signing (Section IV). We evaluate the performance and cost of this implementation on on-site and on-line platforms leveraging end-to-end encryption (Section V).

II Signature

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III Credential

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IV Implementation

In this section we illustrate our implementation of Multidarkroom keygen, sign and verify operations outlining for each:

1. the communication sequence diagram
2. the Zenroom code (Lua dialect)
3. the Zencode statements

In addition to the above, a Setup operation will be briefly illustrated without the sequence diagram, as it includes the local creation of a keypair for the Issuer who will validate the credentials.

Setup: Generate the Issuer keys for credential signature

```
x = INT.random()
y = INT.random()
sk = { x = x,
       y = y  }
vk = { alpha = G2 * x,
       beta  = G2 * y  }
return { sign = sk,
         verify = vk }
```

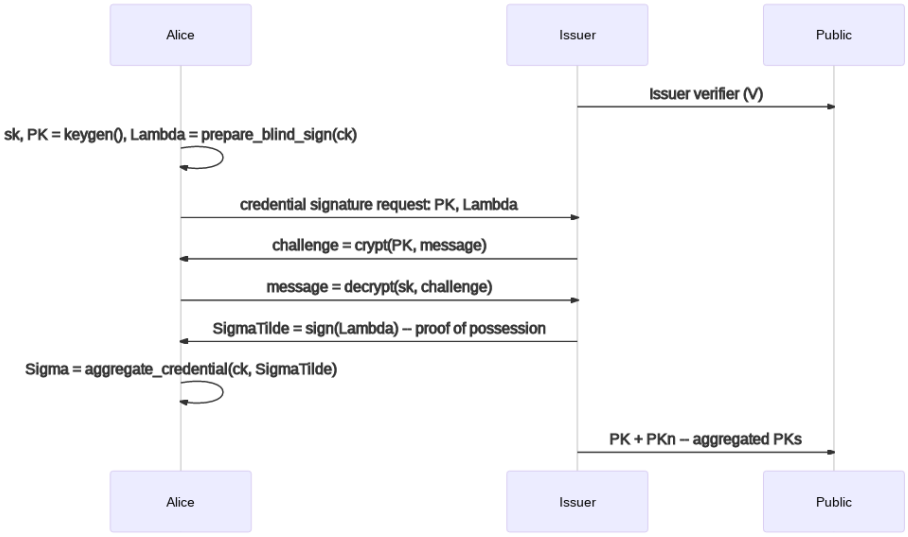
Executed by the Zencode utterance:

When I create the issuer keypair

It will create a new *issuer keypair* that can be used to sign each new *credential request*. Its public member *.verify* should be public and know to anyone willing to verify the credentials of signers.

Keygen: Generate a credential request and have it signed by an Issuer, as well generate a BLS keypair used to sign documents. This procedure will generate private keys that should not be comunicated, as well public BLS keys that can be aggregated for signature verification.

Figure 1: Keygen process sequence diagram



The following Zenroom implementation makes use of the Coconut built-in extension for zero-knowledge proof credentials.

```
ZK = require_once('crypto_abc')
issuer = ZK.issuer_keygen() -- setup
sk = INT.random() -- signing key
ck = INT.random() -- credential key
PK = G2 * sk      -- signature verifier
Lambda = ZK.prepare_blind_sign(ck * G1, ck)
SigmaTilde = ZK.blind_sign(issuer.sign, Lambda)
Sigma = ZK.aggregate_creds(ck, {SigmaTilde})
```

This code is executed in multiple steps by the Zencode utterances:

1. **When I create the credential keypair**
   will create a new *credential keypair* object containing members *public* (ECP) and *private* (BIG).
2. **When I create the credential request**
   will use the *credential keypair* to create a new *credential request* complex schema object for ZK proof.
3. **When I create the credential signature**
   will be executed by the Issuer after the proof-of-possession challenge is positive (exchange and confirmation of an encrypted message using BLS public keys) to sign the credential.
4. **When I create the credentials**
   will aggregate one or more *credential signature* (SigmaTilde) together with the *private* member of the *credential keypair* and finally create *credentials* capable of producing Zero-Knowledge proofs of possession.

Sign:

Verify:

```
---------
-- SETUP
---------
```

Figure 2: Signing process sequence diagram

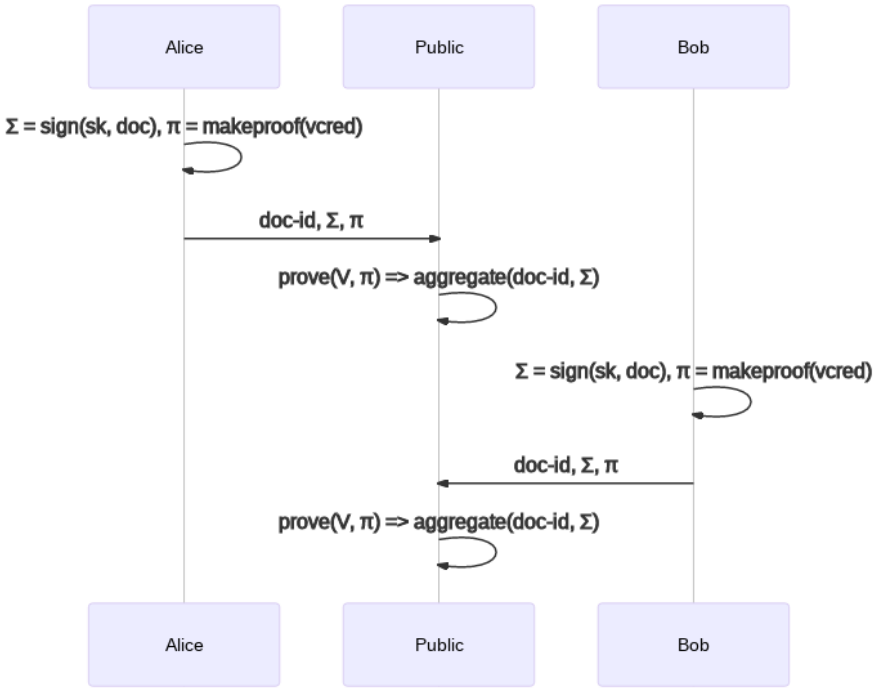
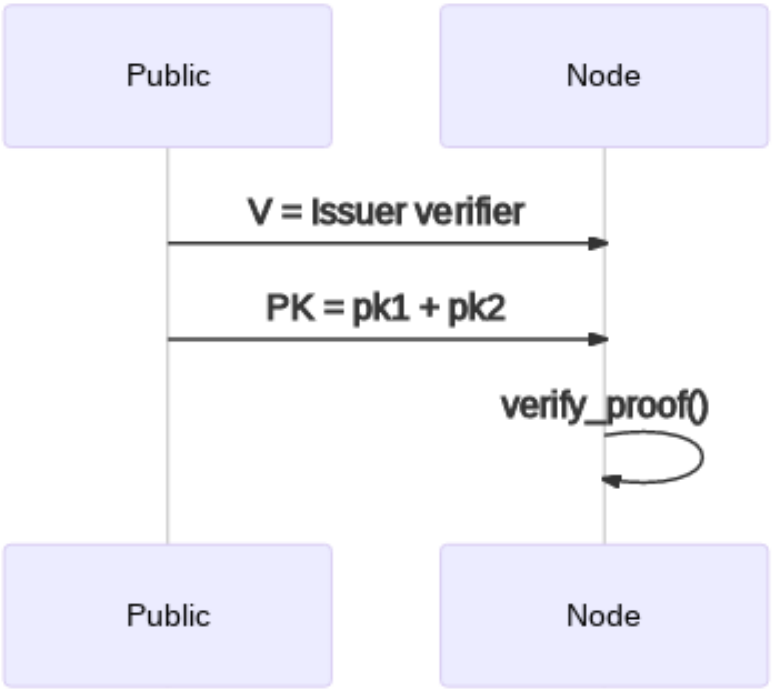


Figure 3: Verification process sequence diagram



```
G1 = ECP.generator()
G2 = ECP2.generator()

-- credentials
ZK = require_once('crypto_abc')
issuer = ZK.issuer_keygen()

-- keygen
sk1 = INT.random() -- signing key
ck1 = INT.random() -- credential key
PK1 = G2 * sk1     -- signature verifier

sk2 = INT.random()
ck2 = INT.random()
PK2 = G2 * sk2

-- issuer sign ZK credentials
Lambda1 = ZK.prepare_blind_sign(ck1*G1, ck1) -- credential request:
p -> i
SigmaTilde1 = ZK.blind_sign(issuer.sign, Lambda1)    -- issuer signs credential:
i -> p
Sigma1 = ZK.aggregate_creds(ck1, {SigmaTilde1})  -- credential sigma
p -> store

Lambda2 = ZK.prepare_blind_sign(ck2*G1, ck2)
SigmaTilde2 = ZK.blind_sign(issuer.sign, Lambda2)
Sigma2 = ZK.aggregate_creds(ck2, {SigmaTilde2})

-- sign

UID = ECP.hashtopoint(msg) -- the message's hash is the unique identifier

--------------
-- SETUP done
--------------

print "-------------------------"
print "first base signing session"
r = INT.random()
R = UID * r      -- session

-- add public keys to public session key
PM = (G2 * r) + PK1 + PK2

-- Session opener broadcasts:
-- 1. R   - base G1 point for signature session
-- 2. PM  - base G2 point for public multi-signature key
-- 3. msg - the message to be signed

-- proofs of valid signature
-- uses public session key as UID
Proof1,z1 = ZK.prove_cred_uid(issuer.verify, Sigma1, ck1, UID)
Proof2,z2 = ZK.prove_cred_uid(issuer.verify, Sigma2, ck2, UID)
-- each signer signs
S1 = UID * sk1
S2 = UID * sk2

-- generate the signature
-- each signer will communicate: UID * sk
```

```
SM = R + S1 + S2


-- print signature contents to screen
I.print({pub = PM, -- session public keys
                   sign = SM,
                   uid = UID,
                   proofhash1 = sha256( ZEN.serialize( Proof1 ) ),
                   proofhash2 = sha256( ZEN.serialize( Proof2 ) ),
                   zeta1 = z1,
                   zeta2 = z2,
                   issuer = issuer.verify
})

-- verify
assert( ZK.verify_cred_uid(issuer.verify, Proof1, z1, UID),
                   "first␣proof␣verification␣fails")
assert( ZK.verify_cred_uid(issuer.verify, Proof2, z2, UID),
                   "second␣proof␣verification␣fails")
assert( ECP2.miller(PM, UID)
                     == ECP2.miller(G2, SM),
        "Signature␣doesn't␣validates")
```

V Evaluation

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VI Bibliography

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