

Anonymous Transactions with Revocation and Auditing in Hyperledger Fabric

Anonymous Credentials, Revocation, Auditing, Blockchain

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Boston University
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Department of Computer Science



BACKGROUND

- Permissioned blockchains explicitly register their participants
logistics network, bank transactions, know-your-customer and anti-money-laundering regulations
- Prove the permission to post a transaction without revealing identity
 - arbitrary length of delegation chain
 - dynamically embedding an arbitrary number of attributes
 - efficient and integrated with the blockchain
- Revocation and audit
 - Prove $AGE \geq 21$ using driving license without revealing your name and issuing state
delegatable anonymous credentials
 - Allow a state to suspend (revoke) the driving license at any time
privacy-preserving revocation
 - Allow a federal investigator to inspect the entire license at a later date with a warrant
auditing along with proving that the credential is “auditable”

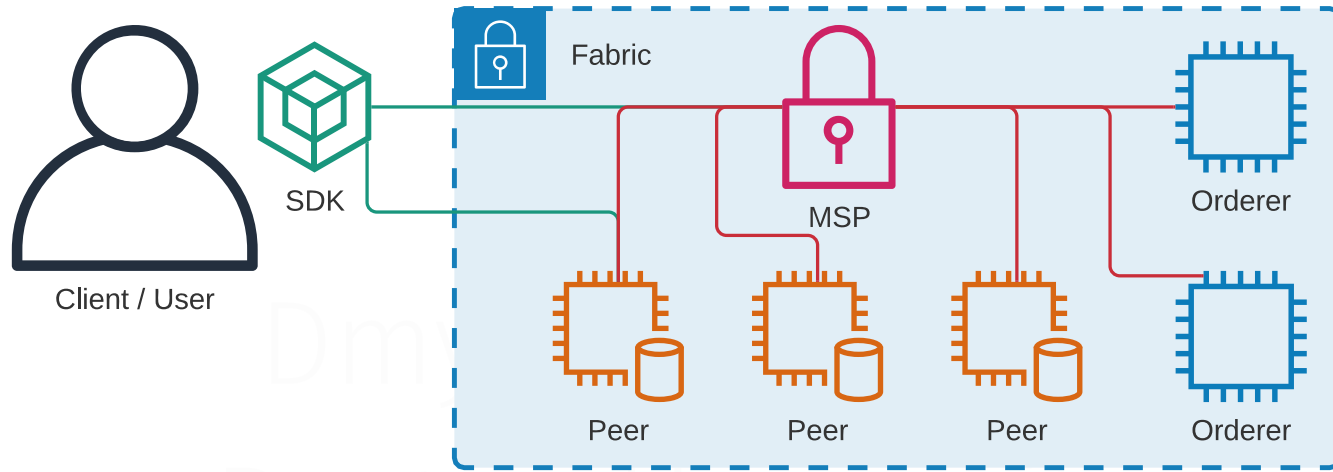


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Components

Clients invoke TXs and observe their results

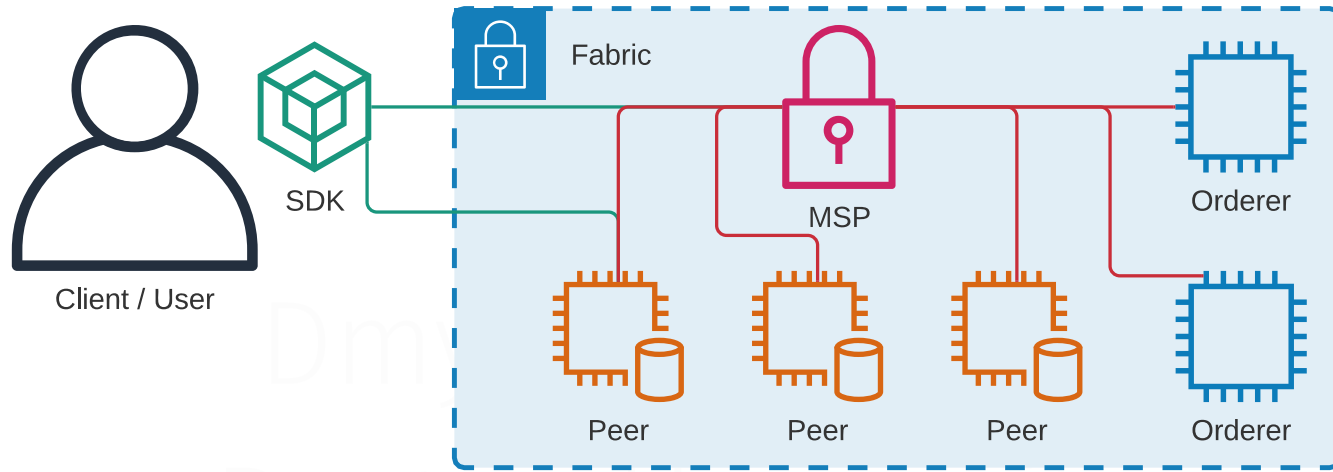
Peers execute and validate TXs

Orderers determine the order of TXs and distribute the blocks to peers

MSP maintains & manages IDs of all members

Execute-Order-Validate

- Client sends TX proposal to endorsers
- Endorsers execute TX, sign read/write sets
- Client prepares TX, sends to orderers
- Orderers puts TX in block, distributes
- All peers validate TX



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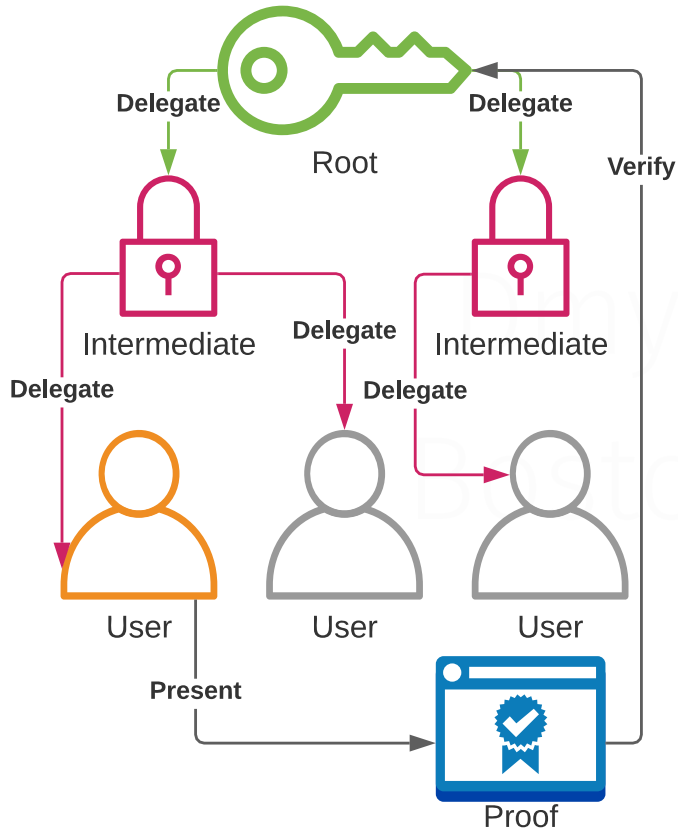
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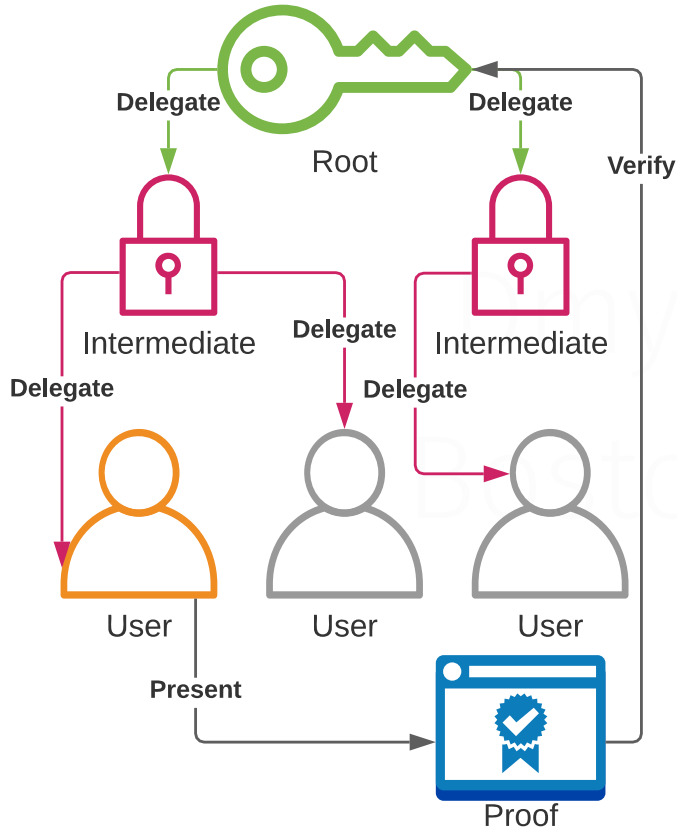
Delegatable Anonymous Credentials [7]



- $\text{KEYGEN}(sp) \rightarrow_s (csk, cpk)$
generate a pair of keys for the caller (root, intermediate, user)
- $\text{DELEGATE}(csk_i, cred_i, cpk_{i+1}, \vec{a}_{i+1}) \rightarrow_s cred_{i+1}$
Level- i authority produces credentials of the Level- $(i+1)$ binding attributes \vec{a}_{i+1} to public key cpk_{i+1}
- $\text{PRESENT}(csk_L, cred_L, cpk_0, \langle a_{i,j} \rangle_{(i,j) \in D}, m) \rightarrow_s \mathfrak{P}_{cred}$
shows the validity of $cred_L$ under cpk_0 , proves that secret key csk_L matches $cred_L$ and disclosed attributes $\langle a_{i,j} \rangle_{(i,j) \in D}$, signs m
- $\text{VERIFY}(\mathfrak{P}_{cred}, cpk_0, \langle a_{i,j} \rangle_{(i,j) \in D}, m) \rightarrow \{0, 1\}$
verifies the correctness of \mathfrak{P}_{cred} relative to disclosed attributes $\langle a_{i,j} \rangle_{(i,j) \in D}$, message m and public key cpk_0
- Instantiated with Groth [5] and Schnorr [1] signature schemes in [7]

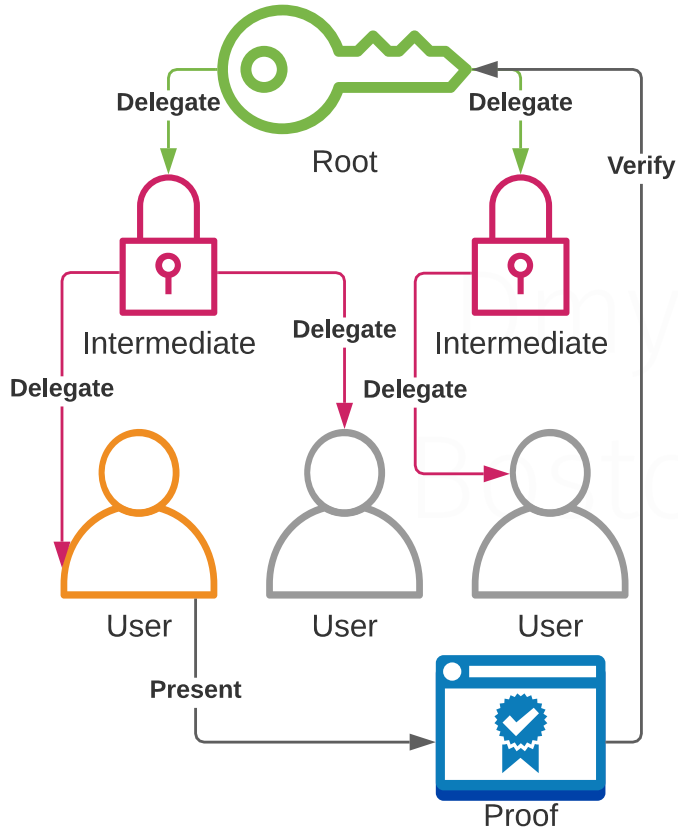


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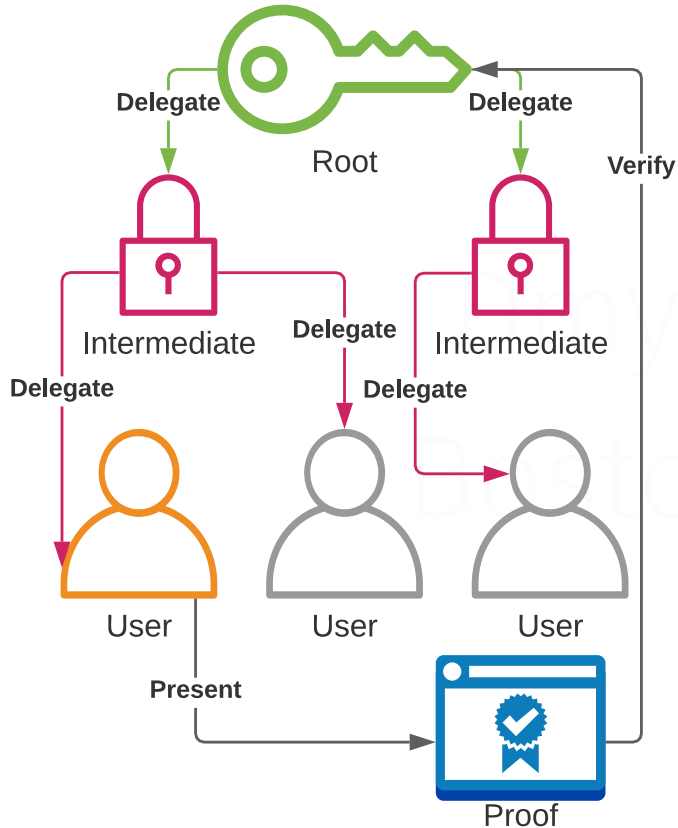
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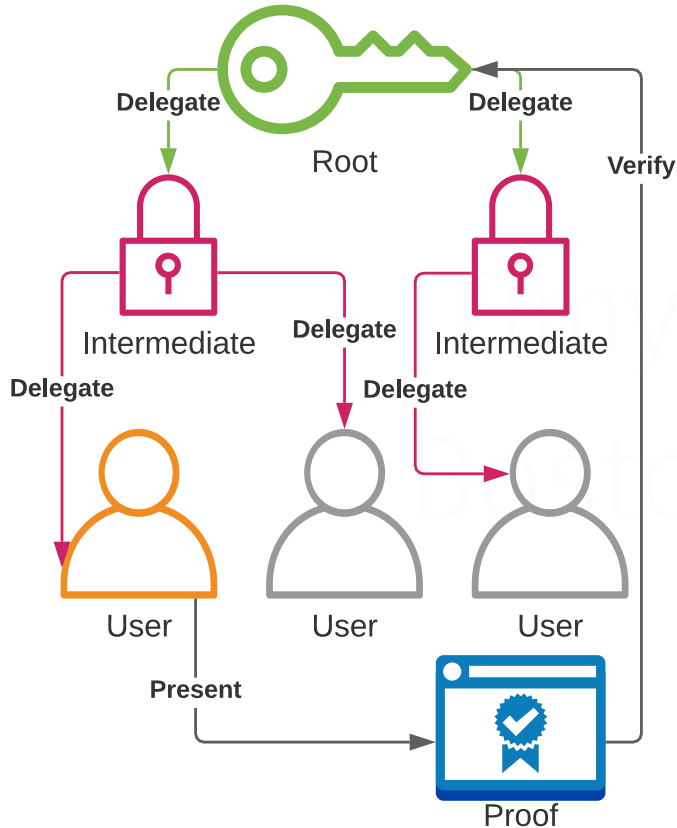
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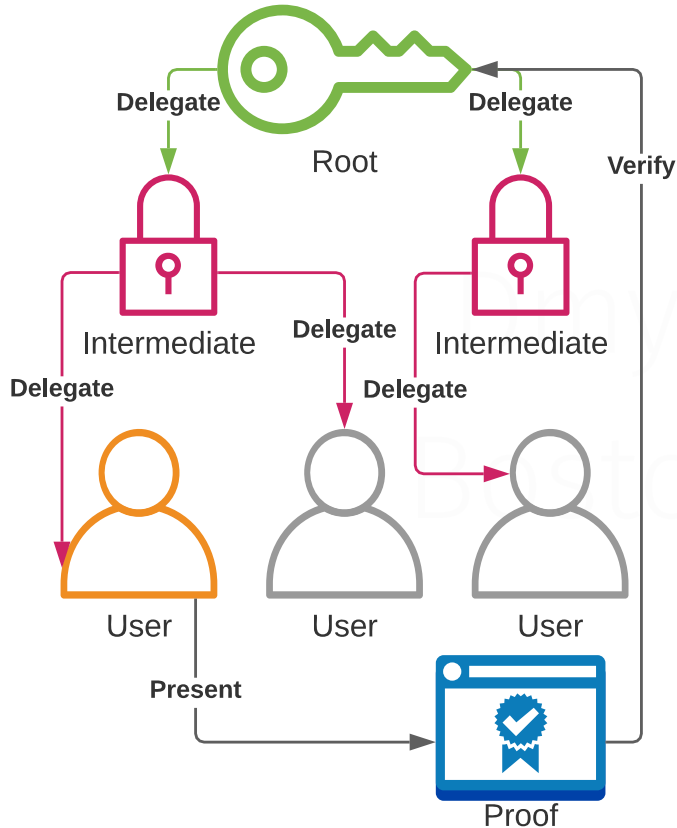
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IMPROVED CONSTRUCTION

General approach

- Revocation is inherently at odds with anonymity
- We couple *epoch-based whitelisting* with signatures in a way that yields efficient proofs of non-revocation
- *Epochs* defined in terms of blockchain height
- *Epoch handle* (signature) binds public key to epoch

$$\mathfrak{P} \leftarrow \text{NIZK}\{(\sigma_{1,\dots,L}, \text{cpk}_{1,\dots,L}, \langle a_{i,j} \rangle_{(i,j) \notin D}, \sigma_m, \sigma) :$$

$$\bigwedge_{i=2,4,\dots,L} \text{GROTH}_1.\text{VERIFY}(\text{cpk}_{i-1}; \sigma_i; \text{cpk}_i, a_{i,1}, \dots, a_{i,n_i})$$

$$\bigwedge_{i=1,3,\dots,L} \text{GROTH}_2.\text{VERIFY}(\text{cpk}_{i-1}; \sigma_i; \text{cpk}_i, a_{i,1}, \dots, a_{i,n_i})$$

Instantiation

- Simple way: epoch as an attribute
- Explicit proof of non-revocation allows to decouple credential issuer and revocation authority

$$\varepsilon := g^{\text{HASH}(\text{epoch})}$$

$$\sigma \leftarrow \text{GROTH.SIGN}(\text{rsk}; \varepsilon, \text{cpk})$$

$$\wedge \text{SCHNORR.VERIFY}(\text{cpk}_L; \sigma_m; m)$$

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General approach

- TX author embeds her ID (public key) encrypted under the auditor's public key
- Prove that the user **encrypts her own public key** and **uses the public key of the authorized auditor**

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Instantiation

- User generates ElGamal secret and public keys ($\text{ask}, \text{apk} = g^{\text{ask}}$)
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Performance optimizations

- Simplified the pseudocode in [7] and corrected mistakes
- Parallelized on the granularity of commitments
- Optimal Miller's loop and final exponentiation

$$\prod_i e(a_i, b_i)^{c_i} = \text{FEXP} \left(\prod_i \hat{t}(a_i^{c_i}, b_i) \right) = \text{FEXP} \left(\prod_i \hat{t}(a_i, b_i^{c_i}) \right)$$

Require: $a_i \in \mathbb{G}_1, b_i \in \mathbb{G}_2, c_i \in \mathbb{Z}_q \cup \perp$ for
 $L = 1, \dots, n$

Ensure: $\text{EPRODUCT}(\langle a_i, b_i, c_i \rangle_{i=1}^n) = \prod_{i=1}^n e(a_i, b_i)^{c_i}$

```
1: procedure EPRODUCT( $\langle a_i, b_i, c_i \rangle_{i=1}^n$ )
2:    $r := 1_{\mathbb{T}} \in \mathbb{G}_{\mathbb{T}}$   $\triangleright$  an identity element
3:   for  $i = (1, \dots, n)$  do
4:     if  $c_i \neq \perp$  then
5:        $a_i := a_i^{c_i}$ 
6:     for  $i = (1, 3, \dots, n)$  do
7:       if  $a_{i+1} \neq \perp$  then
8:          $\triangleright \hat{t}_2$  is a more efficient version of  $\hat{t} \cdot \hat{t}$ 
9:          $r := r \cdot \hat{t}_2(a_i, b_i, a_{i+1}, b_{i+1})$ 
10:      else
11:         $r := r \cdot \hat{t}(a_i, b_i)$ 
12:   return FEXP( $r$ )
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1: procedure EPRODUCT( $\langle a_i, b_i, c_i \rangle_{i=1}^n$ )
2:    $r := 1_T \in \mathbb{G}_T$   $\triangleright$  an identity element
3:   for  $i = (1, \dots, n)$  do
4:     if  $c_i \neq \perp$  then
5:        $a_i := a_i^{c_i}$ 
6:   for  $i = (1, 3, \dots, n)$  do
7:     if  $a_{i+1} \neq \perp$  then
8:        $\triangleright \hat{t}_2$  is a more efficient version of  $\hat{t} \cdot \hat{t}$ 
9:        $r := r \cdot \hat{t}_2(a_i, b_i, a_{i+1}, b_{i+1})$ 
10:    else
11:       $r := r \cdot \hat{t}(a_i, b_i)$ 
12:  return FEXP( $r$ )
```

Setup

1: *Level- i CA*

Level- $(i + 1)$ CA

..... Repeated for L rounds of delegation (from the Root CA to Intermediate CAs to the User)

2: $\text{csk}_i \leftarrow \$ \mathbb{Z}_q, \text{cpk}_i := g^{\text{csk}_i}$

$\text{csk}_{i+1} \leftarrow \$ \mathbb{Z}_q, \text{cpk}_{i+1} := f^{\text{csk}_{i+1}}$

3: $\text{nonce} \leftarrow \$ \{0, 1\}^\lambda$

$\xrightarrow{\text{nonce}}$

$\mathfrak{P}_{\text{pk}} \leftarrow \$ \text{PROVEPK}(\text{csk}_{i+1}, \text{cpk}_{i+1}, \text{nonce})$

4: $\text{VERIFYPK}(\mathfrak{P}_{\text{pk}}, \text{cpk}_{i+1}, \text{nonce})$

$\xleftarrow{\mathfrak{P}_{\text{pk}}, \text{cpk}_{i+1}}$

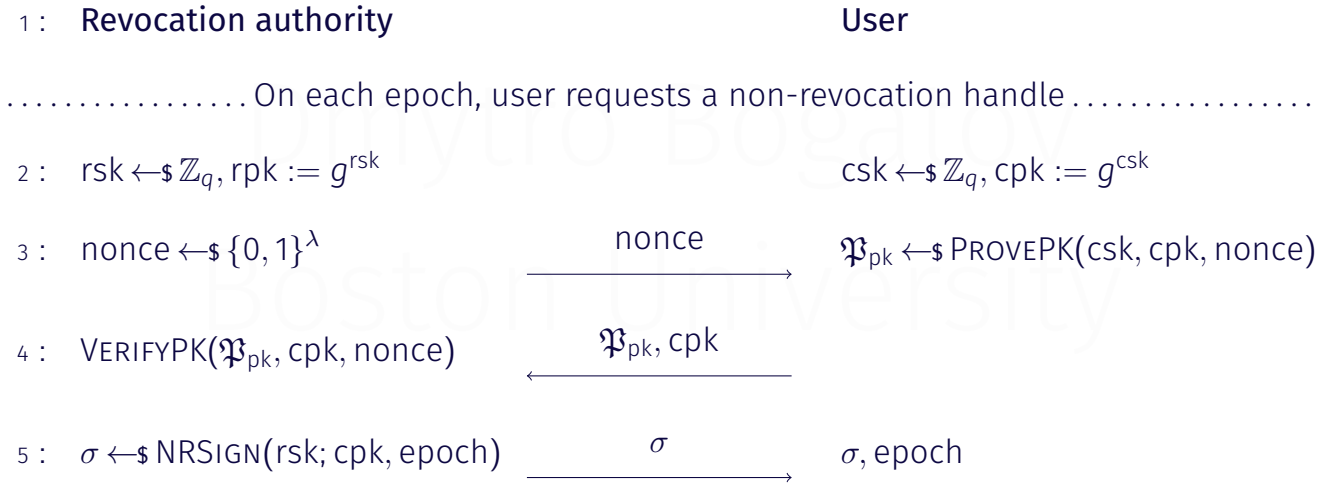
5: $\sigma_{i+1} \leftarrow \$ \text{GROTH.SIGN}(\text{csk}_i; \text{cpk}_{i+1}, \vec{a}_{i+1})$

$\xrightarrow{\sigma_{i+1}}$

$\text{cred}_{i+1} := (\sigma_{i+1}, \vec{a}_{i+1}, \text{cpk}_{i+1})$



Revocation



Transaction submission

1 : Verifier

2 :

User

$\text{cred} := (\langle \sigma_j, \vec{a}_j, \text{cpk}_j \rangle_{j=1}^L)$

..... User submits a transaction

3 :

$\text{enc}, \rho := \text{AUDITENC}(\text{apk}, \text{cpk})$

4 :

$\text{sk}_{\text{nym}}, \text{pk}_{\text{nym}} \leftarrow \$ \text{MAKENYM}(\text{csk})$

5 :

$\mathfrak{P}_{\text{rev}} \leftarrow \$ \text{NRPROVE}(\sigma, \text{csk}, \text{sk}_{\text{nym}}, \text{epoch})$

6 :

$\mathfrak{P}_{\text{audit}} \leftarrow \$ \text{AUDITPROVE}(\text{enc}, \rho, \text{cpk}, \text{csk}, \text{pk}_{\text{nym}}, \text{sk}_{\text{nym}})$

7 :

$\mathfrak{P}_{\text{cred}} \leftarrow \$ \text{CREDPROVE}(\text{cred}, D, \text{sk}_{\text{nym}}, \text{csk}, \perp)$

8 :

$\sigma_{\text{nym}} \leftarrow \$ \text{SIGNNYM}(\text{pk}_{\text{nym}}, \text{sk}_{\text{nym}}, \text{csk}, \text{tx})$

9 : $(\mathfrak{P}_{\text{cred}}, \mathfrak{P}_{\text{rev}}, \mathfrak{P}_{\text{audit}}, \text{enc}, \text{tx}, \text{pk}_{\text{nym}})$

m, σ_{nym}

$m := (\mathfrak{P}_{\text{cred}}, \mathfrak{P}_{\text{rev}}, \mathfrak{P}_{\text{audit}}, \text{enc}, \text{tx}, \text{pk}_{\text{nym}})$

10 : $\text{VERIFYNYM}(\text{pk}_{\text{nym}}, \text{tx}, \sigma_{\text{nym}})$

11 : $\text{NRVERIFY}(\mathfrak{P}_{\text{rev}}, \text{pk}_{\text{nym}}, \text{epoch})$

12 : $\text{AUDITVERIFY}(\mathfrak{P}_{\text{audit}}, \text{enc}, \text{pk}_{\text{nym}})$

13 : $\text{CREDVERIFY}(\mathfrak{P}_{\text{cred}}, D, \text{pk}_{\text{nym}}, \perp)$

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EXPERIMENTAL EVALUATION

- Implemented a stand-alone production-ready library in Go [9]
470 tests cover 100 % of the code
- Apache Milagro Cryptographic Library (AMCL) [11] with a 254-bit Barreto-Naehrig curve [2]
- Benchmarks run on **c2-standard-60** GCE VM running Ubuntu 18.04
all benchmarked operations were run 100 times
- Default number of levels and attributes per level are $L = 2$ and $n = 2$
- Implemented a distributed prototype of Fabric using our scheme
- Setup is different from the base scheme in [7]
- Aiming to answer 6 evaluation questions

Question 1: what is the optimizations' performance benefit?

e-product	Parallelization	CREDPROVE		CREDVERIFY	
		Big	Small	Big	Small
disabled	disabled	2 873	843	1523	948
enabled	disabled	1312	341	853	372
disabled	enabled	1480	357	890	352
enabled	enabled	890	191	391	197
Improvement (\approx times)		3.2	4.4	3.9	4.8

Optimizations benchmark for $L = 2$ and $n = 2$ (small) and $L = 5$ and $n = 3$ (big).
The values are in milliseconds.



Question 2: how does the scheme scale with the number of levels and attributes?

$L \backslash n$	0	1	2	3	4
1	41 ms	51 ms	63 ms	72 ms	82 ms
	89 ms	110 ms	116 ms	153 ms	173 ms
	398 B	534 B	670 B	806 B	942 B
2	94 ms	138 ms	192 ms	255 ms	315 ms
	124 ms	158 ms	198 ms	262 ms	310 ms
	801 B	1.2 kB	1.6 kB	2.0 kB	2.4 kB
3	173 ms	273 ms	367 ms	516 ms	616 ms
	188 ms	249 ms	329 ms	387 ms	427 ms
	1.2 kB	1.7 kB	2.3 kB	2.8 kB	3.3 kB
5	333 ms	542 ms	661 ms	891 ms	1 146 ms
	276 ms	342 ms	391 ms	500 ms	648 ms
	2.0 kB	2.9 kB	3.9 kB	4.8 kB	5.7 kB

Parameters benchmark. In each cell the top value is a proof generation overhead, the middle value is a proof verification overhead and the bottom value is the proof size.



Question 3: what overhead do our extensions impose?

Procedure	Time		Procedure	Time	
	G_1	G_2		G_1	G_2
GROTH.KEYGEN	1.6	4.7	GROTH.SIGN	16	41
GROTH.RANDOMIZE	11	23	GROTH.VERIFY	53	62
SCHNORR.SIGN	1.6	4.8	SCHNORR.VERIFY	2	9.6
AUDITENCRYPT	3	9.4	NRSIGN	14	30
AUDITPROVE	5.8	24	NRPROVE	66	88
AUDITVERIFY	9.2	39	NRVERIFY	127	149
MAKENYM	2.1	9.4	PROVEPK	3.1	9.4
SIGNNYM	2.2	9.9	VERIFYPK	2	9.5
VERIFYNYM	3.5	14	KEYGEN	1.5	4.2

Running time of extensions in milliseconds.

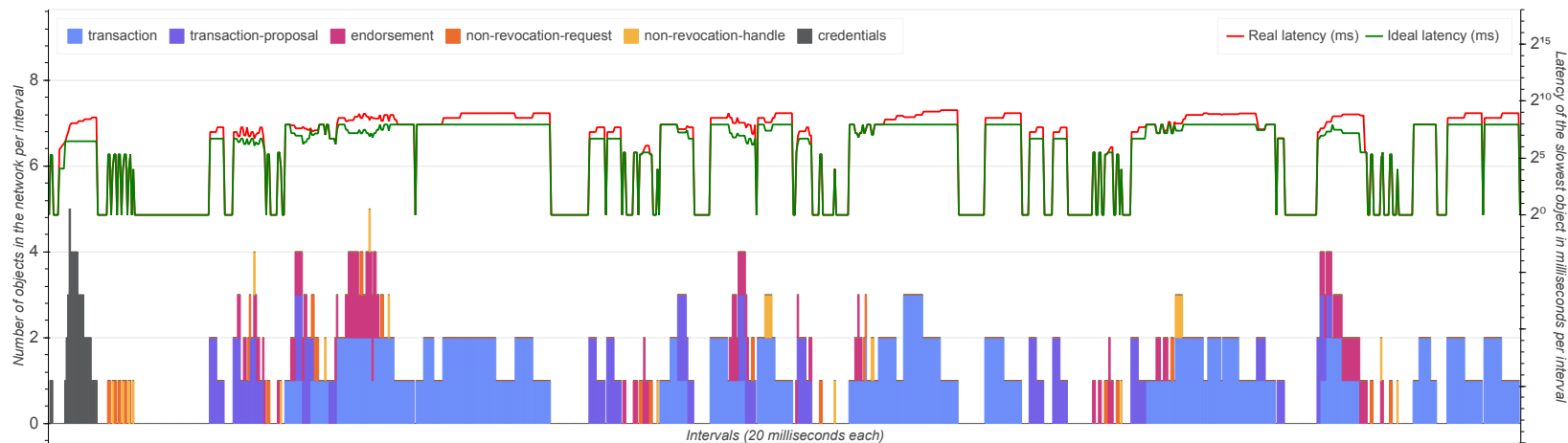


Question 4: how does the system compare to the old non-delegatable idemix?

- Ran workloads against current (non-delegatable) Fabric idemix and regular MSP generating secrets, signing and verifying identities
- Idemix in Fabric [6] uses BBS+ signatures [3]
ran actual Fabric code
- Default (not-idemix) Fabric MSP simply uses X.509 certificates and ECDSA algorithms [4]
ran ECDSA routines in Go `crypto` module using P-384 curve — most secure option in Fabric
- Results show the relative costs of using more privacy-preserving solutions
 - default MSP takes 21 ms
 - idemix MSP in Fabric takes 108 ms
 - our solution takes 210 ms



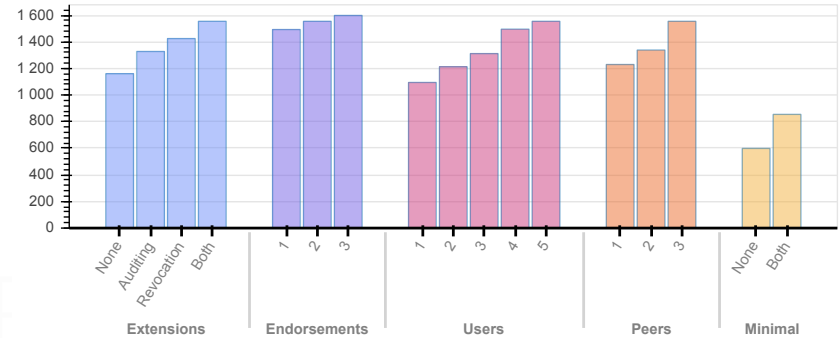
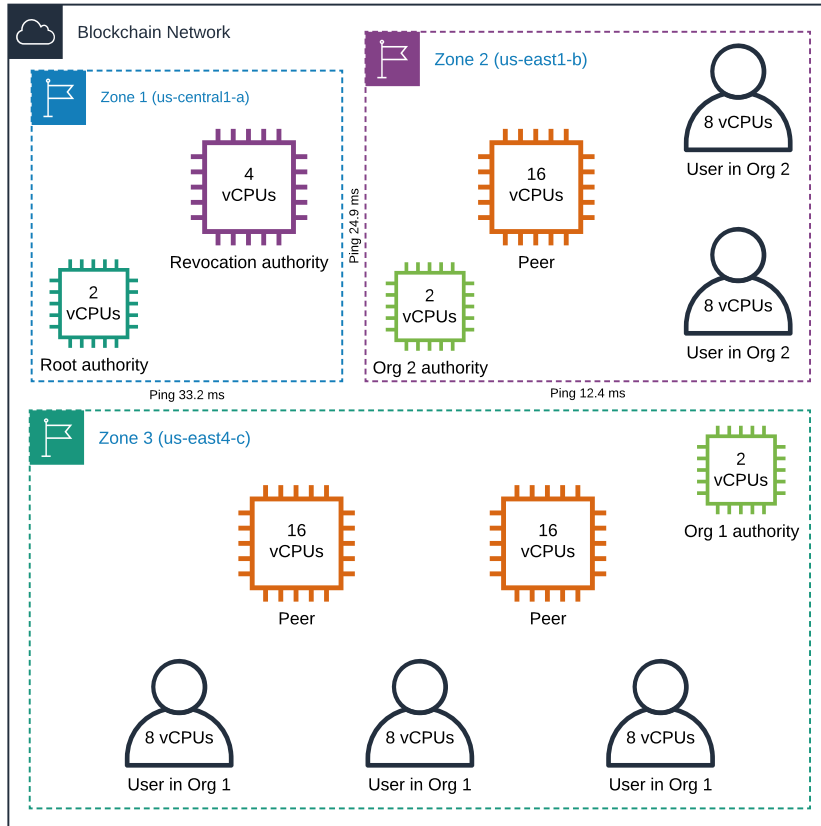
Question 5: how practical is maintaining a single and possibly distributed revocation authority?



Network log visualization (subset is shown, 18 transactions). Interval size is 20 ms. Experiment involves 5 users, 3 peers, 2 endorsements, 20 KiB/s and 50 KiB/s local and global bandwidths, and epoch length 5 seconds. Bars show objects in the network, lines show latencies (green for ideal, red for real). Latency scale is logarithmic.

- Despite short epochs (5 seconds), revocation requests do not result in any spikes in latency
- Overhead of issuing the non-revocation handle is 15 ms–30 ms — a fraction of total overhead
- We observed a stable 200 requests per second throughput on our testing machine

Question 6: what is the efficacy of the entire blockchain stack using our protocol?



- Number of endorsements does not significantly affect the overhead
endorsements are processed in parallel
- Number of users influences the overhead substantially
Each user increases TXs validated by a single peer
- Number of peers is positively correlated with the overhead
TX is completed when the *last* peer validates it

Anonymous Transactions with Revocation and Auditing in Hyperledger Fabric

Anonymous Credentials, Revocation, Auditing, Blockchain

[10] DOI: 10.1007/978-3-030-92548-2_23

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