Zero-Knowledge Proofs for browser-based private authentication to blockchain

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Using existing credentials and MPC-in-the-Head for browser-based private authentication to blockchain

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: Cybernetica AS

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ZKPROOF

Paving the path to adoption

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Authentication in blockchain

Problem

- User wants to post a transaction to the blockchain
  - Authenticated, i.e. signed
- User does not want to manage the private keys

Solution

- Get a JWT from some OAuth provider (Google, Apple, …)
  - Authenticates the user
  - Contains the transaction
- Post the JWT to blockchain

New problem

JWT payload has sensitive fields (name, e-mail, photo, etc)

New solution

zkLogin: Privacy-Preserving Blockchain Authentication with Existing Credentials

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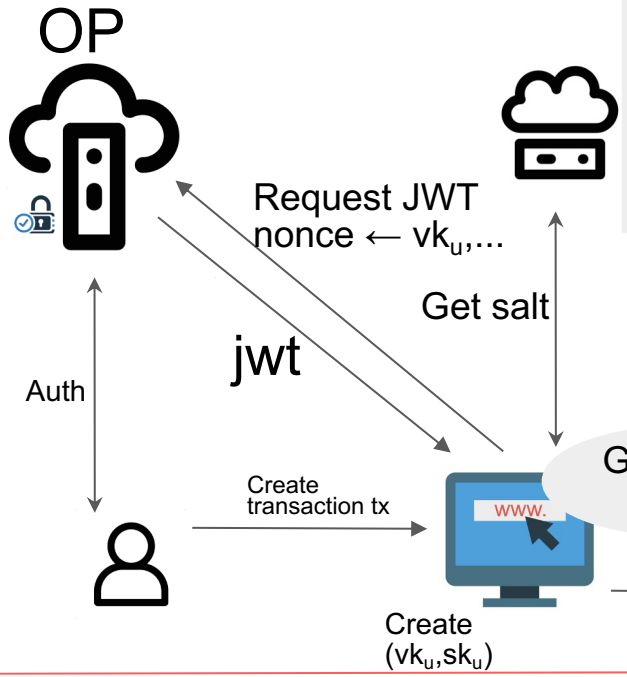
Konstantinos Kryptos Chalkias, Mysten Labs
Yan Ji, Cornell University
Jonas Lindstrøm, Mysten Labs
Deepak Maram, Mysten Labs
Ben Riva, Mysten Labs
Arnab Roy, Mysten Labs
Mahdi Sedaghat, imec-COSIC, KU Leuven
Joy Wang, Mysten Labs

@ CCS 2024

zkLogin flow



$$\text{Ckt}\left(\begin{matrix}\text{zkx} = (\text{pk}_{OP}, \text{iss}, \text{zkaddr}, T, vk_u),\\ \text{zkw} = (\text{jwt}, \text{salt}, r)\end{matrix}\right):$$
$$\text{zkaddr} = H(\text{jwt.stid}, \text{jwt.aud}, \text{jwt.iss}, \text{salt}) \text{ and } \text{jwt.iss} = \text{iss} \text{ and}$$
$$\text{jwt.nonce} = H(vk_u, T, r) \text{ and } JWT.\text{Verify}(\text{pk}_{OP}, \text{jwt}).$$

Parse jwt

- RSA or ECDSA verify
- SHA256

Problem

- Proof generation is expensive
- zkLogin outsources the generation

Generate
zkp

Groth16

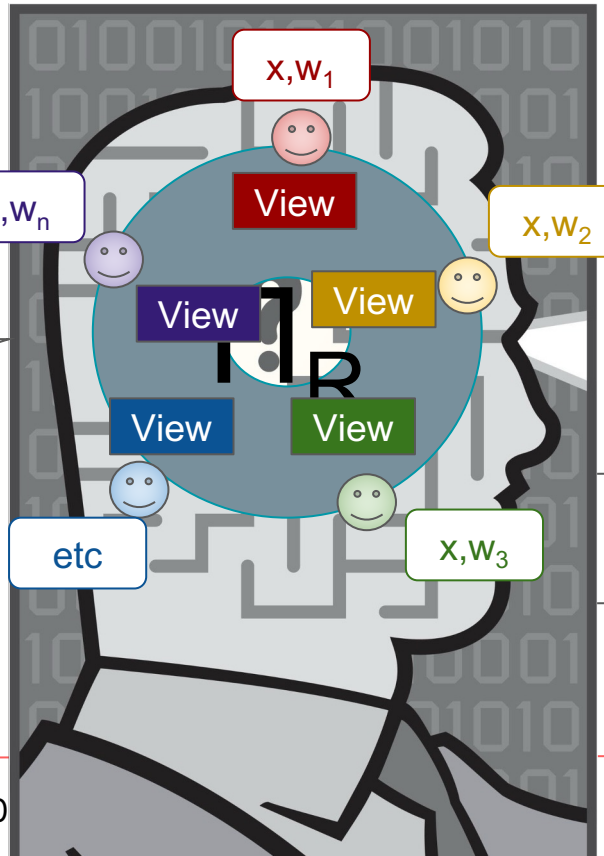
Post tx, vk$_u$, T, sig(sk$_u$, tx), zkp

Motivation + “Research question”

- Alphabill blockchain: https://github.com/alphabill-org/alphabill
  - Sharded ledger with heterogeneous rules; fast consensus with “root→shard” trust in validation; programmability via WASM
  - Was developed by Guardtime
- Can the proof be generated in browser?
  - By using some other NIZK technique, perhaps non-succinct?
- CHESS: Cyber Security Excellence Hub in Estonia and South Moravia
  - Partners include Cybernetica, Guardtime, [many more]

CHESS

MPC in the Head (MPCitH)



Witness w ∈ **W**

Secret Share

$w_1, w_2, \ldots, w_n$

x,w_n

Relation R, where R : **X** × **W** → {0,1}

Instance x ∈ **X**

Secure against **two passive** corruptions

$\Pi_R(x; w_1,\ldots,w_n) = R(x,w)$

Com(View), Com(View), …, Com(View)

■, ■

View, View

FS

- Output = 1?
- Consistent?

Soundness error < $1 - 1/n^2$

CYBERNETICA

Why would MPCitH be suitable?

- Computations in “zkLogin relation” are heterogeneous:
  - Signature verification: large fields
  - Hash function (in signature verification): bits
    - More freedom to choose some other hash functions
  - Parsing: characters, i.e. 8-bit values
  - Base64 encoding: 6- and 8-bit values
- Passively secure MPC can match that heterogeneity

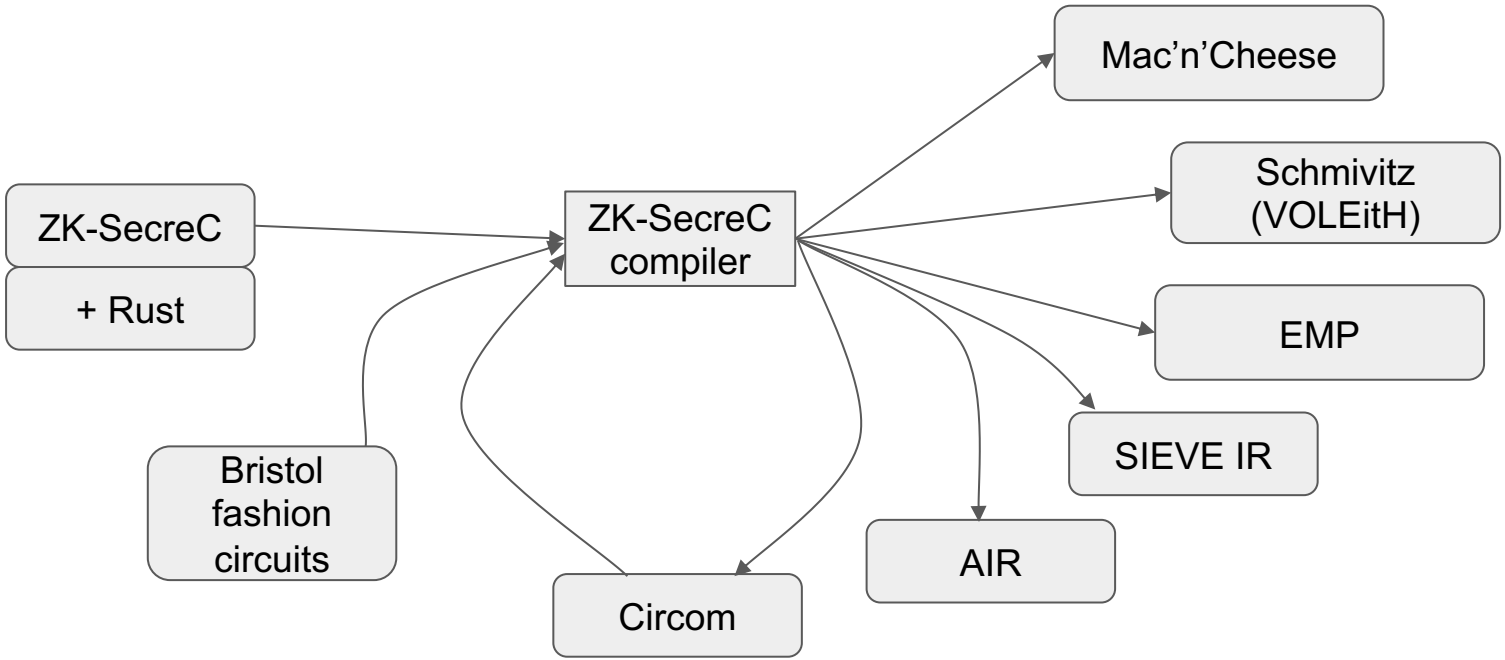
MPCitH implementations in Github

- ZKB++
  - Very simple protocol
  - A bit of documentation
  - Can read the paper and the code in parallel
    - Consisted of ca. 6k LoC of C++
- Katz-Kolesnikov-Wang
  - No documentation. Could not get it to run

ZK-SecreC

- DSL for statements one may want to prove in zero-knowledge
- Information-flow type system, with two dimensions:
  - Is a value known only to prover, or also to verifier? Or is it a public constant?
  - Is a value held locally? Or {{managed by the ZKP technique}}?
- Imperative language. Some useful control-flow constructions
- A variety of data types (for “integers”)

ZK-SecreC toolchain



Support for many rings in ZKB++

- Supported so far: $\mathbb{Z}_M$, M is a k-bit prime, where $k \in \{3,...,272\}$
- Also supported so far: $GF(2^k)$, where $k \in \{3, 17, 33, 65\}$

Our additions

- $\mathbb{Z}_p$ for p the size of P-256 & P-384 prime fields, and EC groups
- $\mathbb{Z}_M$ for $M \in \{2^{32}, 2^{64}\}$
- $\mathbb{Z}_{2^k}$ for $k \in \{1, \ldots, 64, 256, 384\}$ (specialized $\mathbb{Z}_{2^{32}}$ and $\mathbb{Z}_{2^{64}}$)
- Elliptic curve *groups* (specialized P-256 & P-384)
- The use of several rings at the same time
  - MPCitH protocol to convert between rings

Support for rings in ZK-SecreC type system

n :: Nat
∞ :: Nat

uint :: Nat → Unqualified
bool :: Nat → Unqualified

- uint[n] is $\mathbb{Z}_n$. uint[∞] is $\mathbb{Z}$
- bool[n] is booleans, but compatible with uint[n]

The kind for “pure” data types

bitwise :: Nat → Ring
plain :: Nat → Ring
int :: Ring → Unqualified
bin :: Ring → Unqualified

- uint[n] ≡ int[plain[n]]
- bool[n] ≡ bin[plain[n]]

- ZK-SecreC uses SIEVE IR’s “Circuit Configuration Communication” syntax
  - Compiler learns capabilities of the ZKP back-end
    - rings, conversions, plugins…
- This has been extended

Elliptic curve groups: “undocumented API calls”

Interesting parts of the relation

$$\mathrm{Ckt}\left(\begin{matrix}\mathrm{zkx} = (\mathrm{pk}_{OP}, \mathrm{iss}, \mathrm{zkaddr}, T, vk_u),\\ \mathrm{zkw} = (\mathrm{jwt}, \mathrm{salt}, r)\end{matrix}\right):$$
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- Parsing JWT (correct JSON only, coming from OP)
  - Slicing an array, running checks on that slice
- Base64 encoding / decoding
- SHA-256 computation
- ECDSA verification (no RSA)

Our contributions to implementing these parts

Array slicing

- Recursive approach to pointing out the location of the slice
- Asymptotically decreases the size of the relation

Base64

- More efficient formula for conversion
- Bit-parallel execution

ECDSA verification

- Nothing in particular…
  - Leverage the implementation of various rings for ZKB++
  - Sharing over EC group reduces proof size

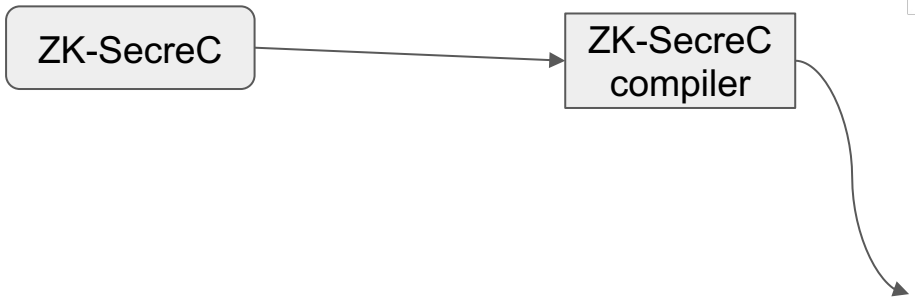
SHA-256

- Bit-parallel execution of the rounds of the compression function
- Bit-parallel execution of block finishes
  - Careful scheduling, supported by ZK-SecreC

More additions to ZKB++

- Multiple instance and witness values
- Multiple output values
  - Π_R for the relation R “accepts” if all outputs are 0
- Declassification and random number generation in the MPCitH protocol
- Serialization and deserialization of the proof

ZK-SecreC — ZKB++ integration



ZKB++ (and our additions)

```
CircuitContainer* c = new CircuitContainer();
```

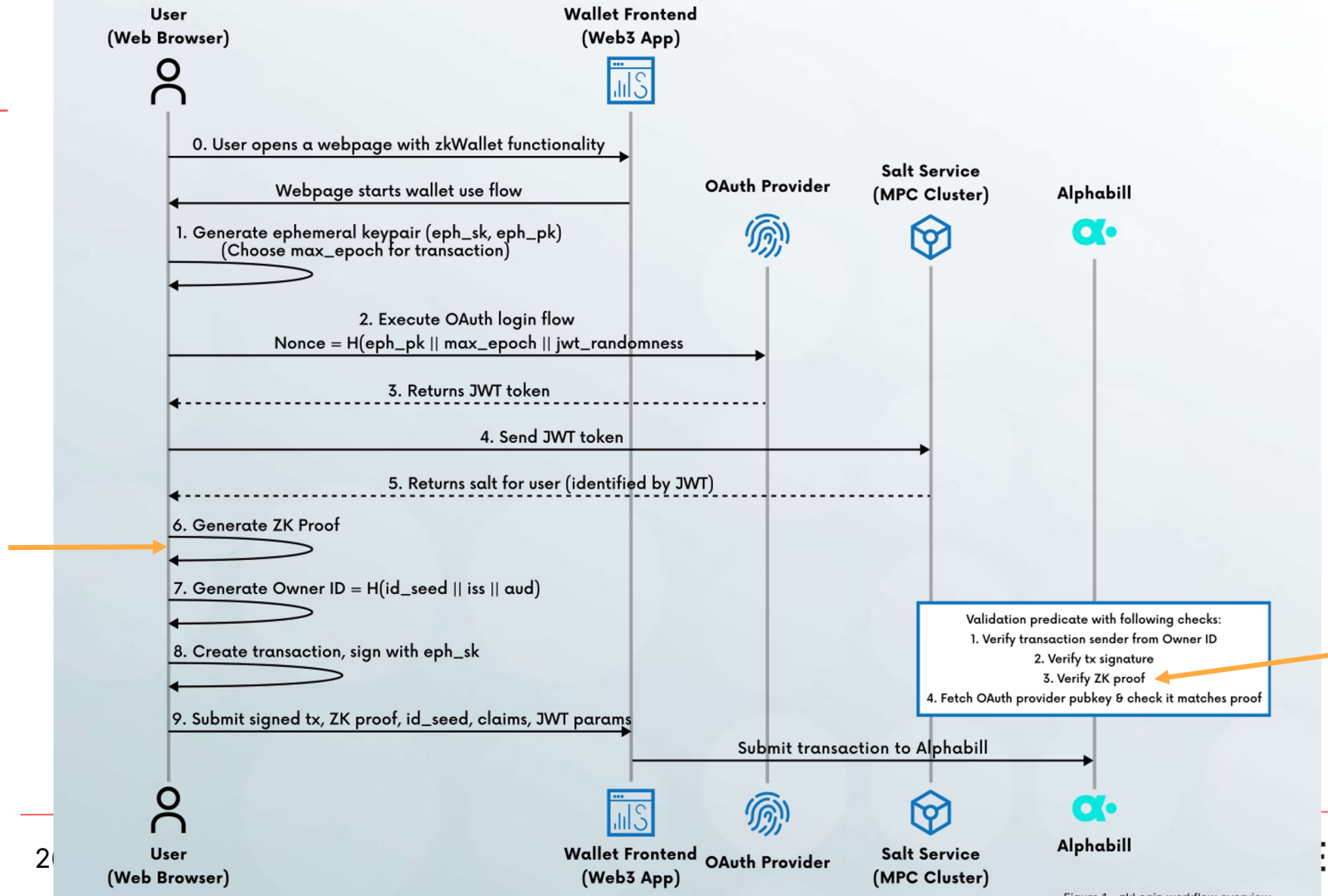
```
CircuitContainer::CircuitContainer() {

}

CircuitContainer::~CircuitContainer() {
  if(this->value_shares_ != NULL) {
    for(uint32 i = 0; i < this->party_size_; i++) {
      delete[] this->value_shares_[i];
```

Benchmarks (local execution)

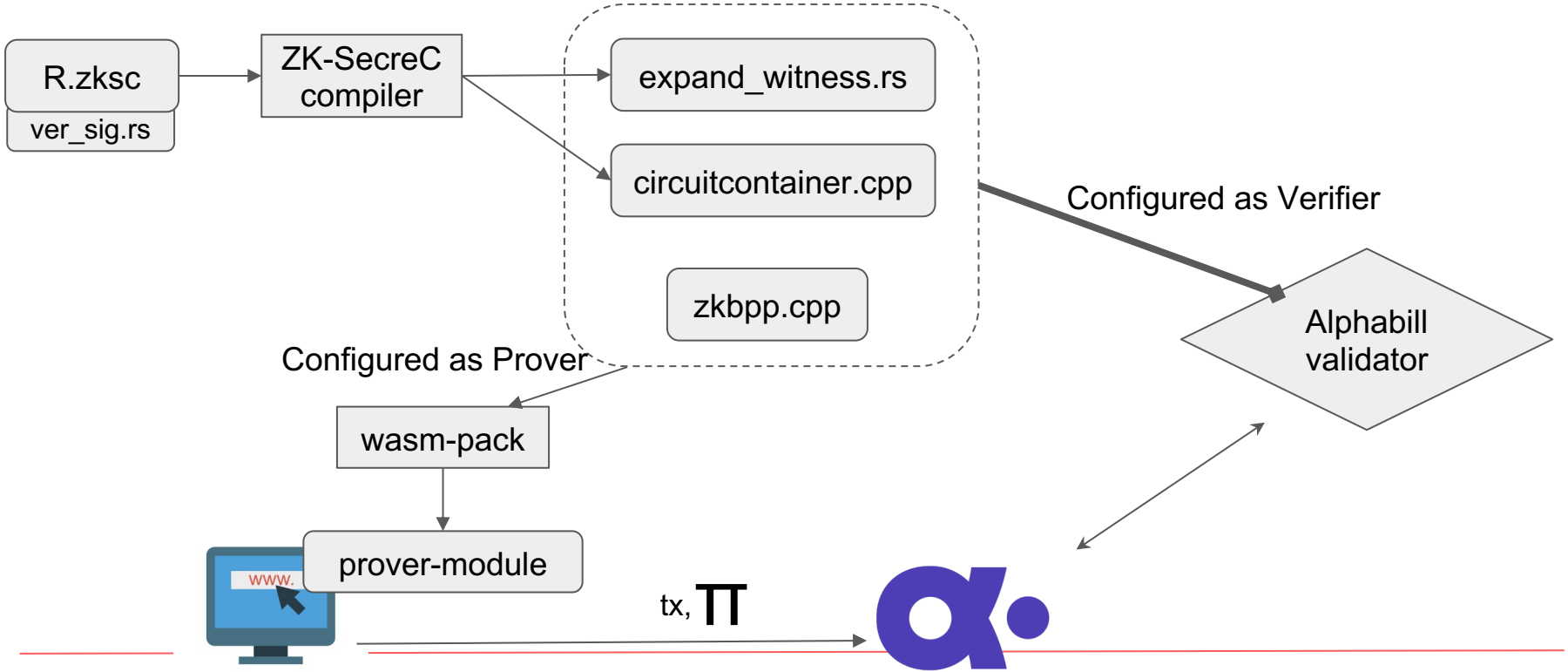
	prover	verifier	witn. expand	size
init + parse + check + base64	0.45s	0.32s	0.09s	15.8 MB
… + SHA	1.49s	1.09s	0.12s	45.5 MB
Full circuit with 256-bit ECDSA in ZKSC	2.06s	1.48s	0.18s	66.2 MB
Full circuit with 256-bit ECDSA in ZKB++	2.08s	1.5s	0.33s	49.1 MB
Full circuit with 384-bit ECDSA in ZKSC	2.54s	1.77s	0.25s	90.1 MB
Full circuit with 384-bit ECDSA in ZKB++	3.01s	2.11s	0.6s	50.8 MB

Execution on a 2-year old laptop

1472-byte payload. Fixed-length payloads and header. Variable-length adds ca 10%


User
(Web Browser)
Wallet Frontend
(Web3 App)
OAuth Provider
Salt Service
(MPC Cluster)
Alphabill
0. User opens a webpage with zkWallet functionality
Webpage starts wallet use flow
1. Generate ephemeral keypair (eph_sk, eph_pk)
(Choose max_epoch for transaction)
2. Execute OAuth login flow
Nonce = H(eph_pk || max_epoch || jwt_randomness
3. Returns JWT token
4. Send JWT token
5. Returns salt for user (identified by JWT)
6. Generate ZK Proof
7. Generate Owner ID = H(id_seed || iss || aud)
8. Create transaction, sign with eph_sk
9. Submit signed tx, ZK proof, id_seed, claims, JWT params
Validation predicate with following checks:
1. Verify transaction sender from Owner ID
2. Verify tx signature
3. Verify ZK proof
4. Fetch OAuth provider pubkey & check it matches proof
Submit transaction to Alphabill
User
(Web Browser)
Wallet Frontend
(Web3 App)
OAuth Provider
Salt Service
(MPC Cluster)
Alphabill

Running in browser + blockchain



Benchmarks (browser)

Full circuit with 256-bit ECDSA in ZKB++

	witn. exp.	Prover
Firefox 150.0.1 (64bit)	0.4s	4.5s
Chrome 147.0.7727.137 (64-bit)	0.4s	4.3s

CPU: AMD Ryzen 7 PRO 8840U
OS: NixOS, kernel 7.0.3

Thank you

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