Regulation-Friendly Privacy-Preserving Blockchain Based on zk-SNARK

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TOC

Introduction

- A blockchain is a **distributed ledger** technology consisting of a growing list of records, called blocks, that are securely linked together using cryptography.
- Blockchain has the characteristics of **decentralization, tamper proofing, and traceability.**
- Blockchain can establish a trust relationship among different parties and has played an important role in the fields of **finance, insurance, medical care, and supply chain security.**

Introduction

Privacy

- Blockchain users in fields such as finance and medical care **do not** want their sensitive data stored on the blockchain ledger to be fully openly accessed.
- Internal data of enterprises and institutions **should not** be accessible to other collaborators without authorization.

Regulation

- Internal auditors in most companies **should** always have information about how the business is doing.
- Industries such as telecommunications and banking **must** provide information such as communication records and transaction details to the court when they receive a legal request.

Related Work

Privacy

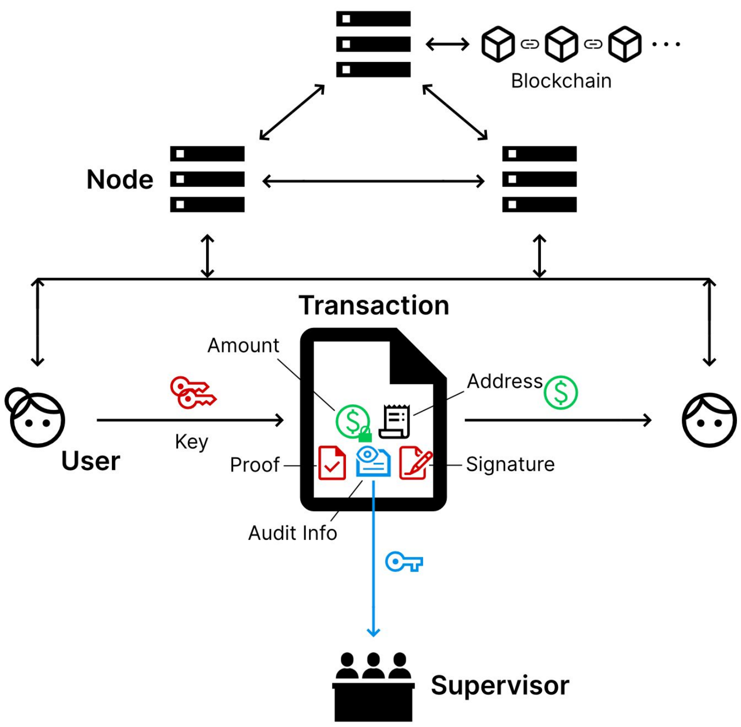
- Ring Signature
  - Monero
- Stealth Address
  - Monero
- Zero-Knowledge Proof
  - Zcash
  - Zether
- Mixing
  - Dash

Regulation

- Zero-Knowledge Proof
  - DAP
  - PAChain
  - RDAP
- Group Signature
  - PPChain
- Verifiable Encryption

Overview

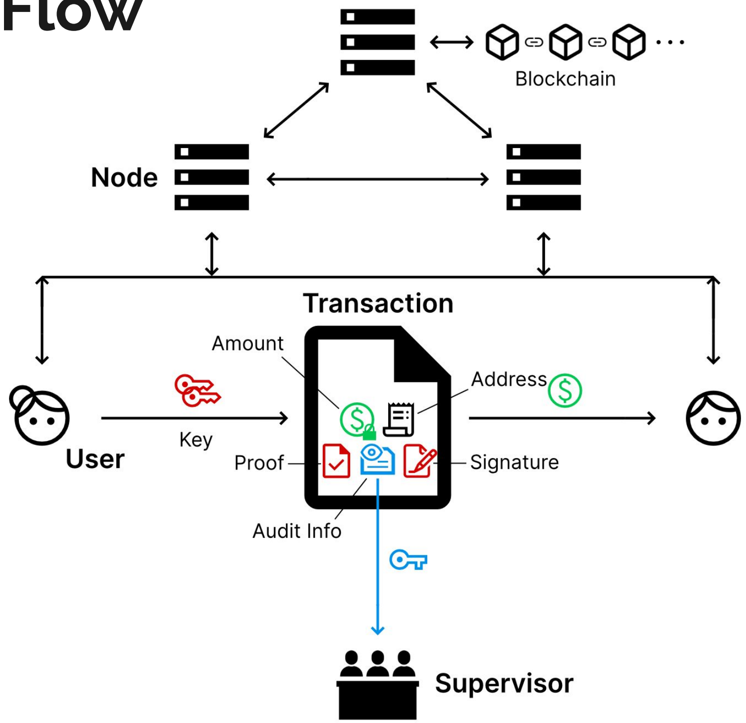
- **Account model** instead of UTXO model
- **Homomorphic encryption** to hide the transaction amounts and account balances of sender and receiver
- **Address obfuscation** to hide the identity information of both parties
- **Zero-knowledge proof** to ensure the validity of the transaction
- Supervisors can decrypt transaction details for **regulatory audit** purposes



Design Details of Transaction Flow

Transfer

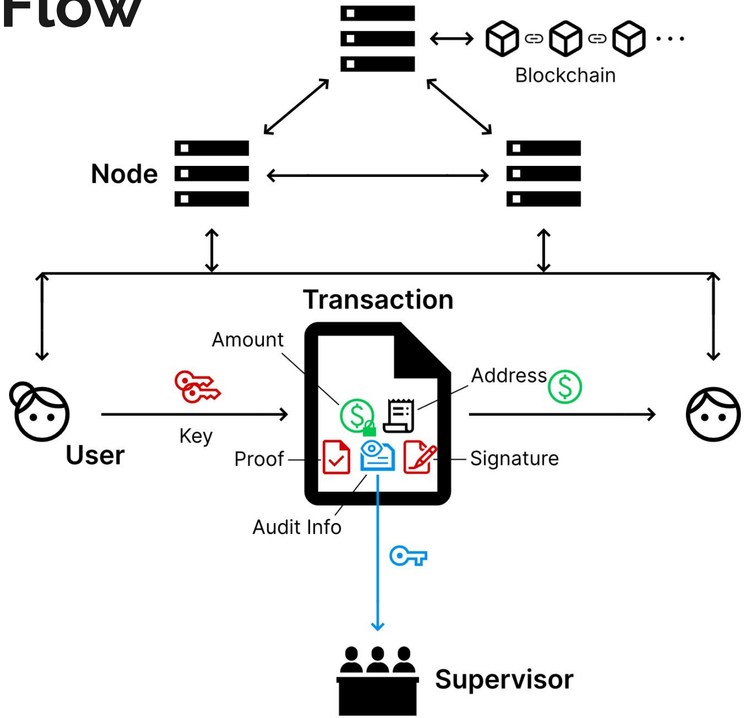
- The sender uses the private key to generate **one-time keys** and encrypts the amount with the public key
- Create **obfuscated addresses,** mixed with sender and receiver addresses
- The sender encrypts the amount, balance, its public key, and the receiver's public key with the supervisor's public key as **audit information**
- The sender uses the **zk-SNARK protocol** to prove that the transaction is valid and contains audit information, and uses a **one-time** signing key to generate a signature
- The sender constructs the transaction to call the smart contract, and the smart contract verifies the signature and zero-knowledge proof
- The smart contract uses the **homomorphic** property to update the balance of both parties and the balance of the obfuscated addresses



Design Details of Transaction Flow

Audit

- The supervisor obtains the encrypted audit information from the transaction
- Decrypts it using its private key
- Checks whether the transaction complies with regulatory rules



Design Details of Transaction Flow - ZKP

- The transfer amount a and balance b' of the transaction sender are **non-negative**
- All a-related ciphertexts are well-formed and encrypt the same value **a**
- All -a-related ciphertexts are well-formed and encrypt the same value **-a**
- All v-related ciphertexts are well-formed and encrypt the same value **0**
- **Audit information** is properly encrypted with the supervisor public key

$$\pi : \{(\mathsf{pk}, \overline{\mathsf{pk}}, \mathsf{sv}, \mathsf{pk_k}, C_L, C_R, C, D, \overline{C},$$

$$C'_L, C'_R, C', D', \overline{C'}, C_{L,k}, C_{R,k}, C_k, D_k, \overline{C_k},$$

$$C_a, C_{b'}, g; \mathsf{sk}, a, b', r) :$$

$$a \in [0, \mathsf{Max}] \wedge b' \in [0, \mathsf{Max}] \wedge$$

$$C = g^a \mathsf{pk}^r \wedge \overline{C} = g^a \overline{\mathsf{pk}}^r \wedge D = g^r \wedge$$

$$C_L / C = g^{b'} (C_R / D)^{\mathsf{sk}} \wedge$$

$$C' = g^{-a} \mathsf{pk}^r \wedge \overline{C'} = g^{-a} \overline{\mathsf{pk}}^r \wedge D' = g^r \wedge$$

$$C'_L / C' = g^{b'} (C'_R / D')^{\mathsf{sk}} \wedge$$

$$C_k = g^v \mathsf{pk_k}^r \wedge \overline{C_k} = g^v \overline{\mathsf{pk_k}}^r \wedge D_k = g^r \wedge$$

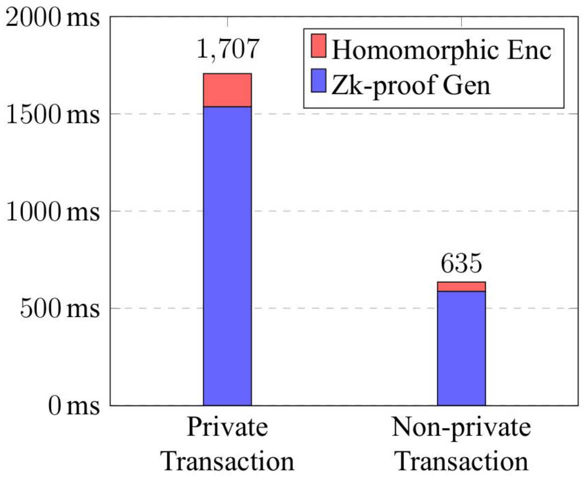
$$C_{L,k} / C_k = g^{b'} (C_{R,k} / D_k)^{\mathsf{sk}} \wedge$$

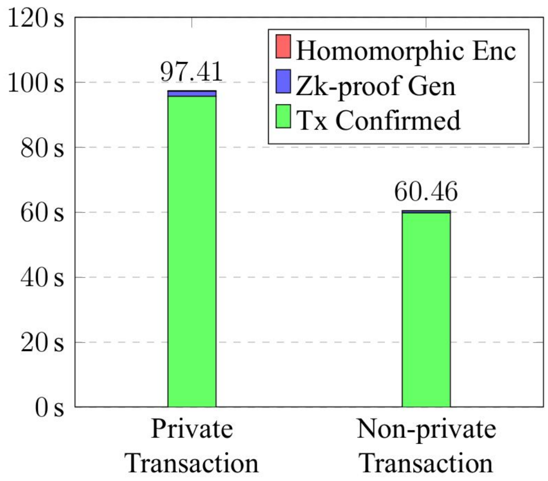
$$v = 0 \wedge \mathsf{pk} = g^{\mathsf{sk}} \wedge$$

$$C_a = g^a \mathsf{sv}^r \wedge C_{b'} = g^{b'} \mathsf{sv}^r \wedge$$

$$C_{\mathsf{pk}} = g^{\mathsf{pk}} \mathsf{sv}^r \wedge C_{\overline{\mathsf{pk}}} = g^{\overline{\mathsf{pk}}} \mathsf{sv}^r\}, \forall k \in [0, n]$$

Performance Analysis





- The time consumed by cryptographic operations such as homomorphic encryption and zero-knowledge proof is short enough, and the performance of private transactions is acceptable.
- Compared with non-private transactions, the additional computation required by private transactions is not time-consuming and will not become a significant bottleneck.

Conclusion

- The innovation of the proposed system lies in the use of the account model and zk-SNARK protocol, the regulatory process is efficient and easy to use, taking into account the needs of privacy protection and regulatory support, and the time overhead is low.
- The proposed system can further expand the application scenarios of blockchain and play a role in industries with strict regulatory requirements and high privacy protection requirements.

Thanks

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