Integration of MPC into Besu through an extended private transaction model

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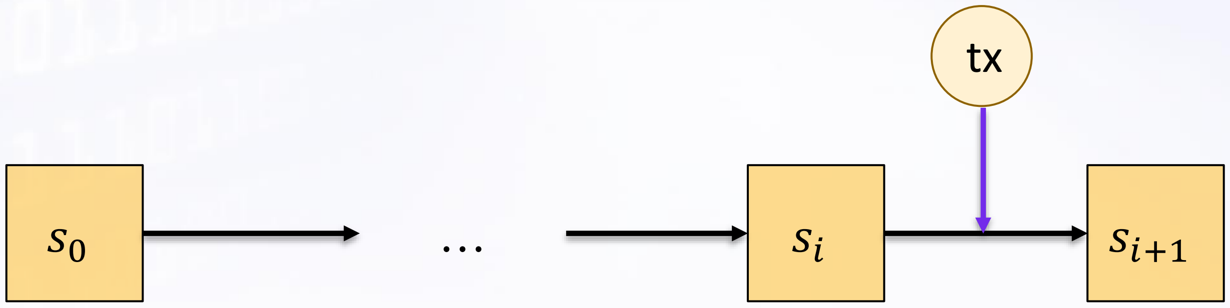
Introduction

- What is a Blockchain?
  - Decentralized network
  - Immutable storage
  - Data integrity
  - Byzantine Fault Tolerant Consensus protocols (PoW, PoS, PoA…)
- Use cases
  - Financial, e-government, voting, medical, metaverse…
- Generalization: State Transition System
  - $(S, \rightarrow)$, with S the set of all possible states and $\rightarrow$ the relation between states
  - $APPLY(s_i, tx) \rightarrow \{s_{i+1} \vee error\}$



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Privacy problem and related work

- Privacy/confidentiality problem
  - Every data must be public to enable verifiability
  - End-users can be profiled and deanonymized
  - Many use cases work with personal/sensitive data, e.g., biometrics
- Solutions
  - Cryptocurrencies
    - Mixers: break the link between sender and receiver
  - Smart contracts
    - Quorum / Besu: private transactions between a specific subgroup
  - Privacy by design
    - Arbitrum: off-chain computation of private data
    - Hawk: privacy based on Zero Knowledge Proofs
    - Oasis Network / Secret Network: privacy based on Trusted Execution Environments

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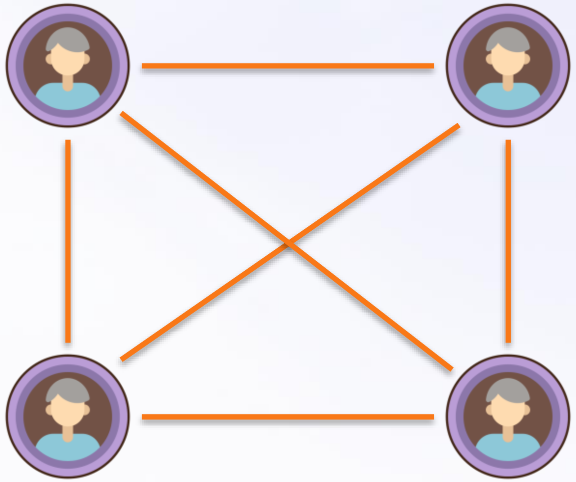
MPC – Decentralized confidential computations

- Secure Multi-Party Computation (MPC)
  - Why MPC?
    - Decentralized cryptographic protocols
    - Enable computation on encrypted data
  - A set of parties $\{P_1, \dots, P_n\}$ jointly compute a function $f(\cdot)$ on private data $\{x_1, \dots, x_n\}$
  - **Correctness**
    - The parties involved in the computation obtain the desired output correctly, i.e., MPC computes $y \leftarrow f(x_1, \dots, x_n)$ and nothing else
  - **Privacy**
    - Party P_i does not learn anything but x_i and y



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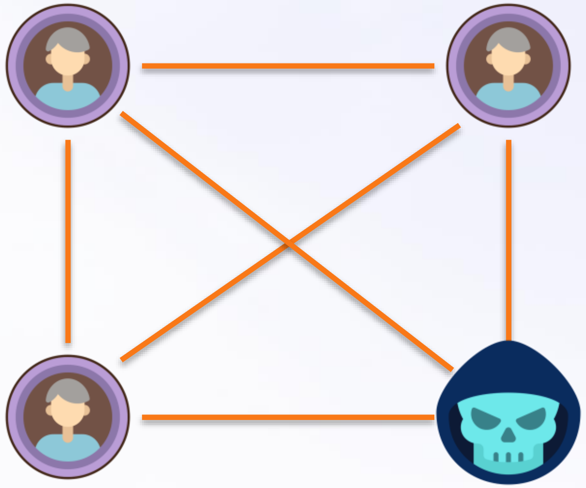
  - MPC is secure even if some parties are malicious



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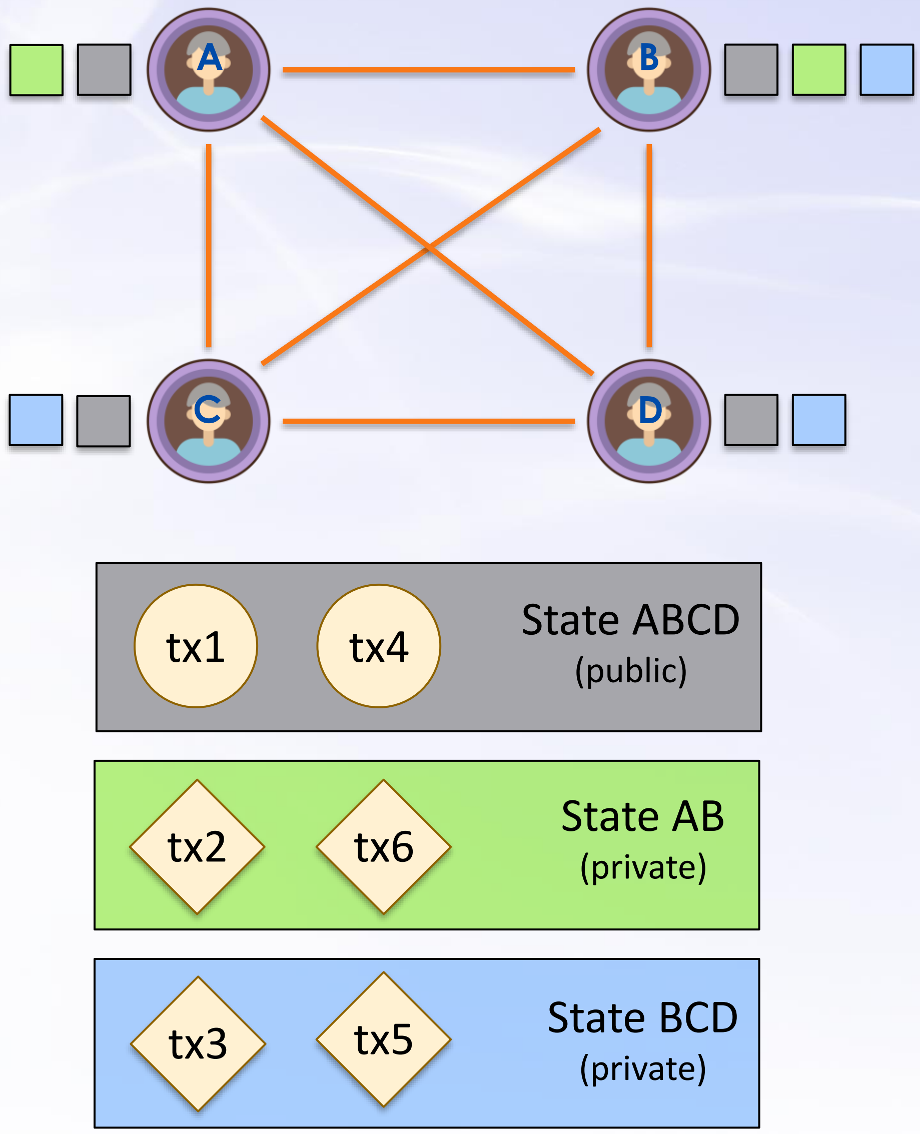
Hyperledger Besu - Definitions

- Why Hyperledger Besu?
  - An Ethereum blockchain client
  - Permissioned network
  - Supports private transactions

- Privacy group
  - A **subgroup of the blockchain** network whose nodes share the **same view of the state**
  - A private transaction is only visible to a specific privacy group
  - Extended state of one node:

$$S_{ext} = S_{pub} \cup \left(\bigcup_{N \in P} S_N^P \right)$$



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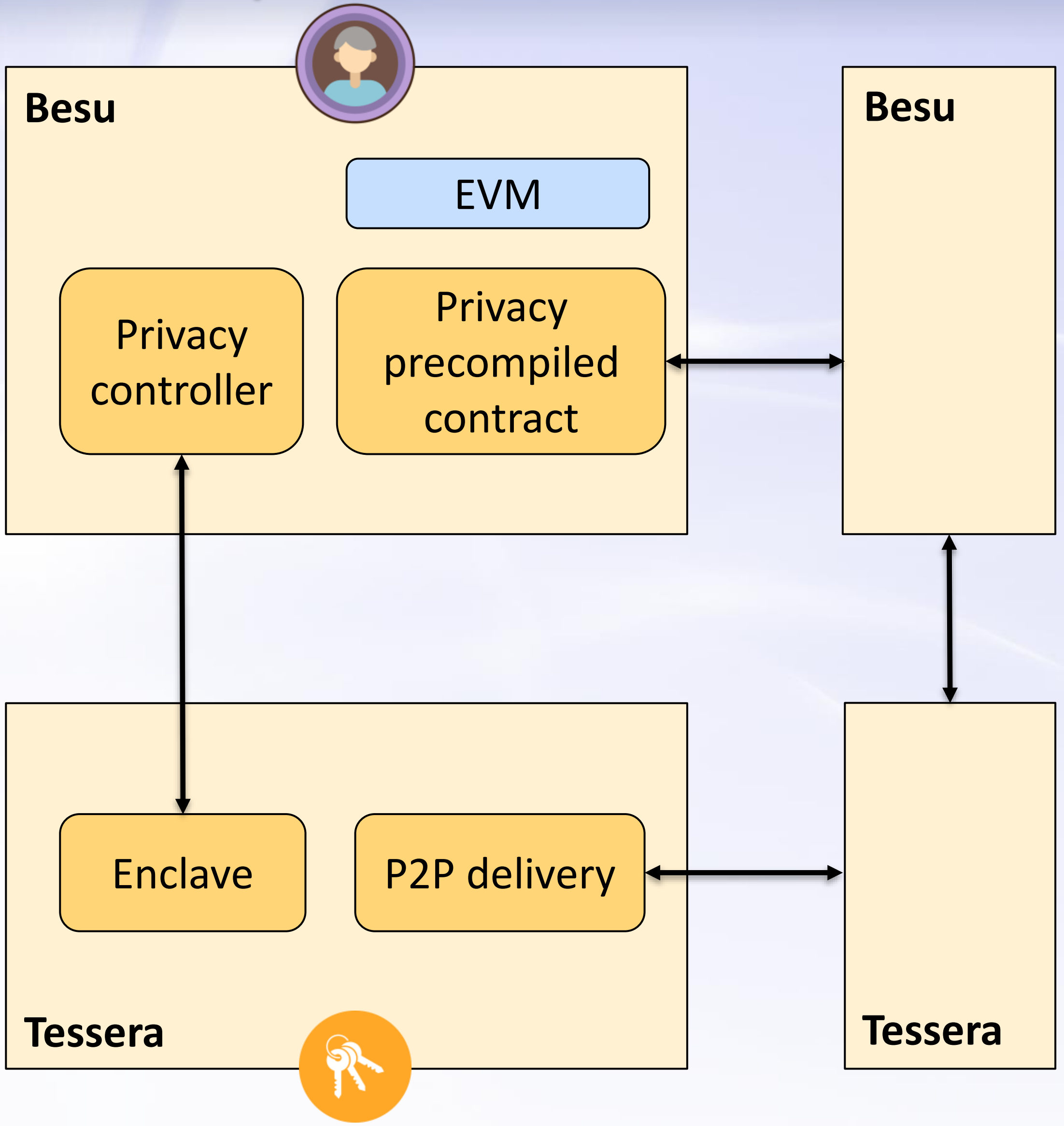
Hyperledger Besu – Main components

- Private transaction manager (Tessera)
  - Performs private transaction delivery
- Privacy controller
  - Manages private transactions in Besu and communicates with the private transaction manager
- Privacy precompiled contract
  - A special purpose Smart contract that resides inside Besu and manages private transaction execution



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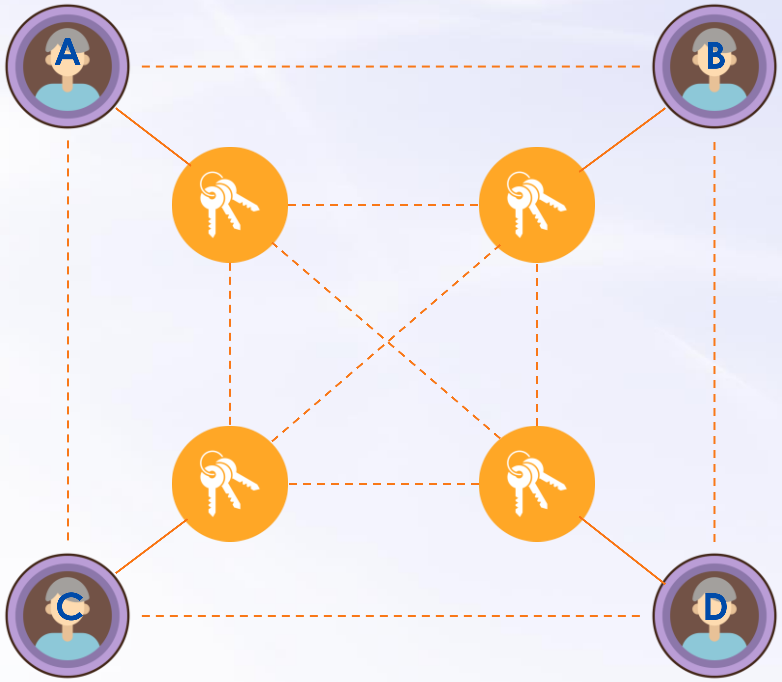
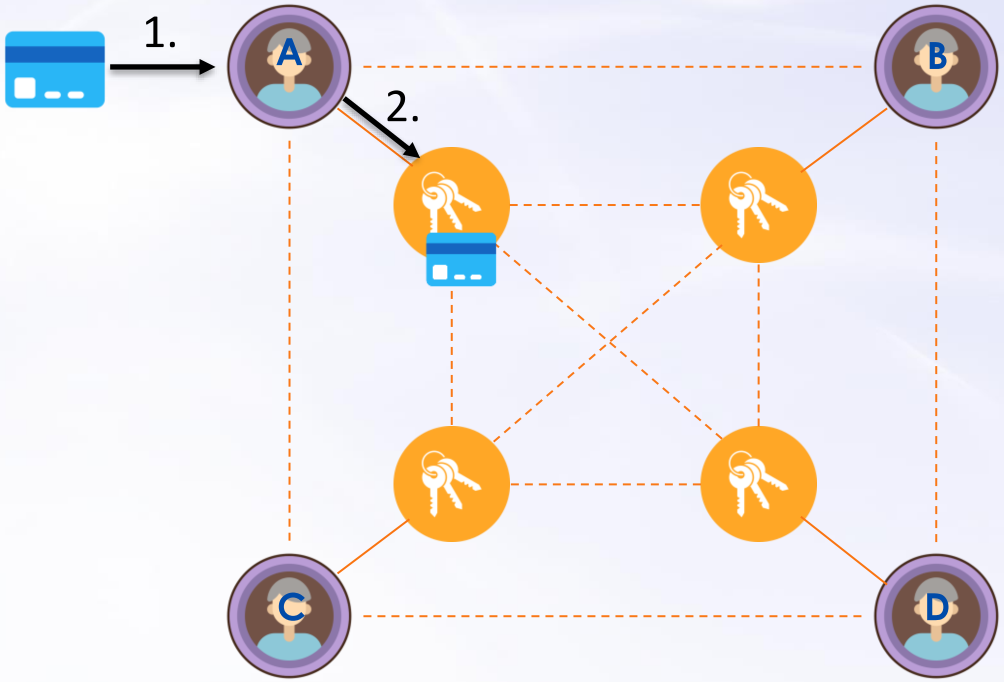
Hyperledger Besu - Example

- Sending private transactions in Hyperledger Besu



Hyperledger Besu - Example

- Sending private transactions in Hyperledger Besu
  - 1. New transaction
    - From: A
    - To: BC
  - 2. Send transaction



Hyperledger Besu - Example

- Sending private transactions in Hyperledger Besu
  - 1. New transaction
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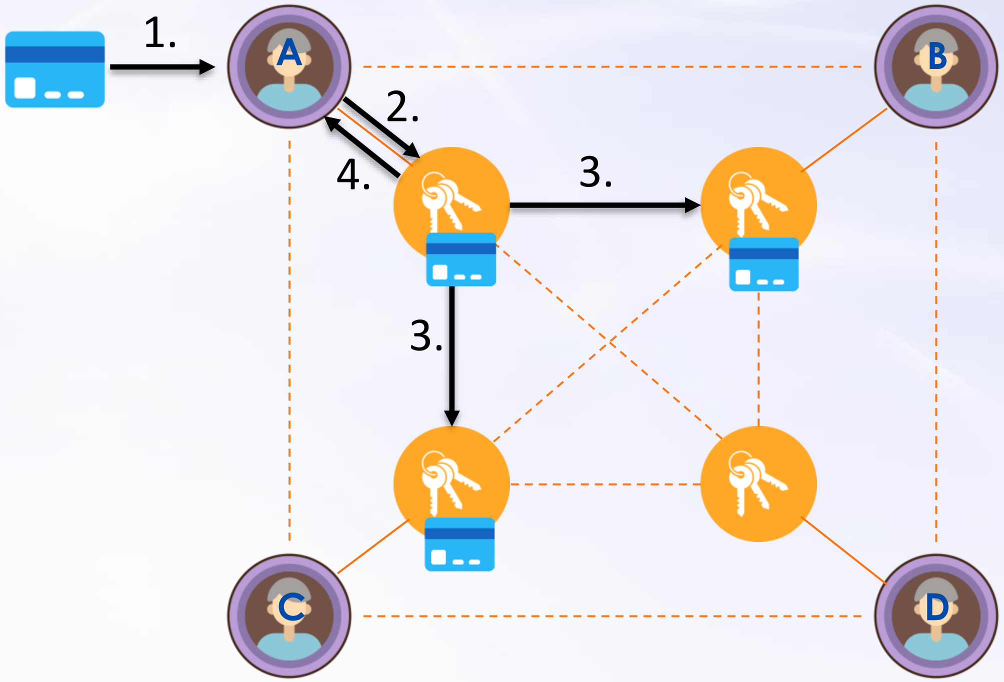
  - 3. Push transaction
  - 4. Receive key (pseudorandom ID)



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Hyperledger Besu - Example

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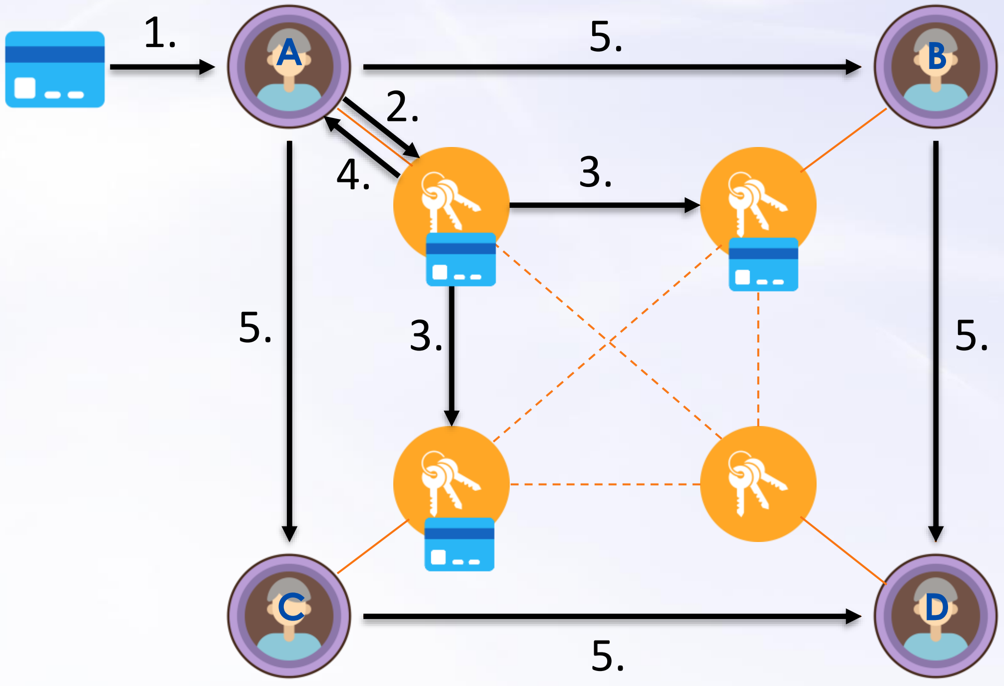
  - 5. Flood Privacy Marker Transaction



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Hyperledger Besu - Example

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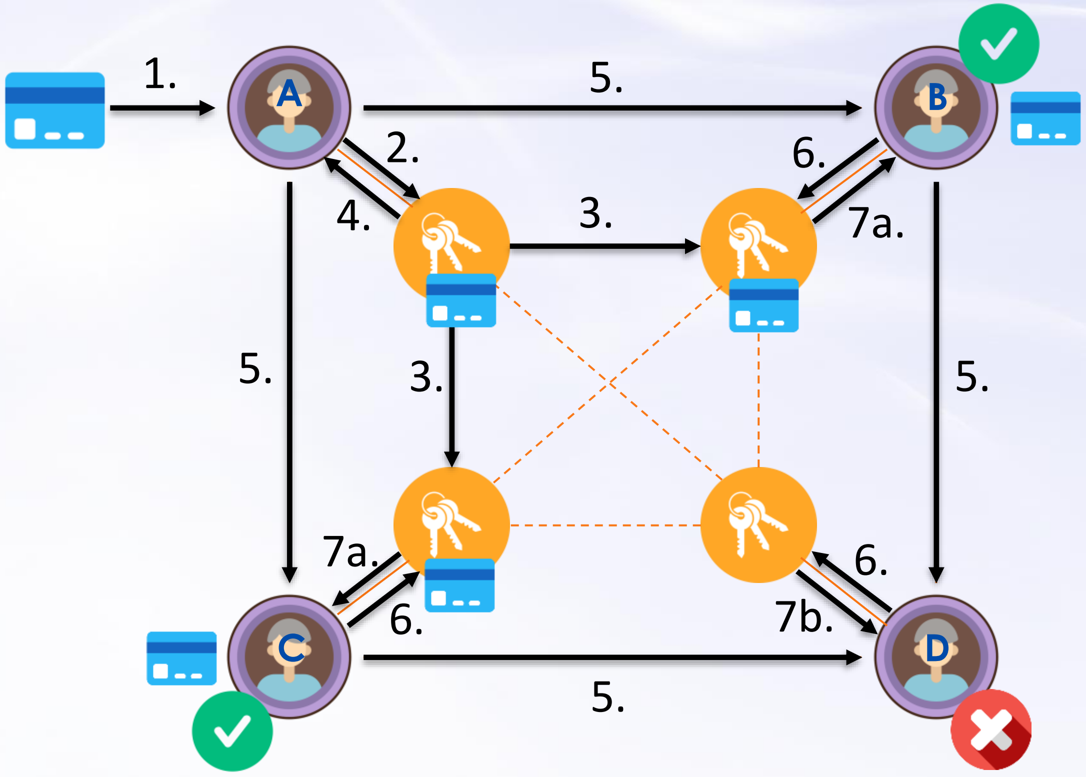
  - 2. Send transaction
  - 3. Push transaction
  - 4. Receive key (pseudorandom ID)
  - 5. Flood Privacy Marker Transaction
  - 6. Query Private Marker Transaction
  - 7a. OK: transaction available
  - 7b. ERROR: transaction not available



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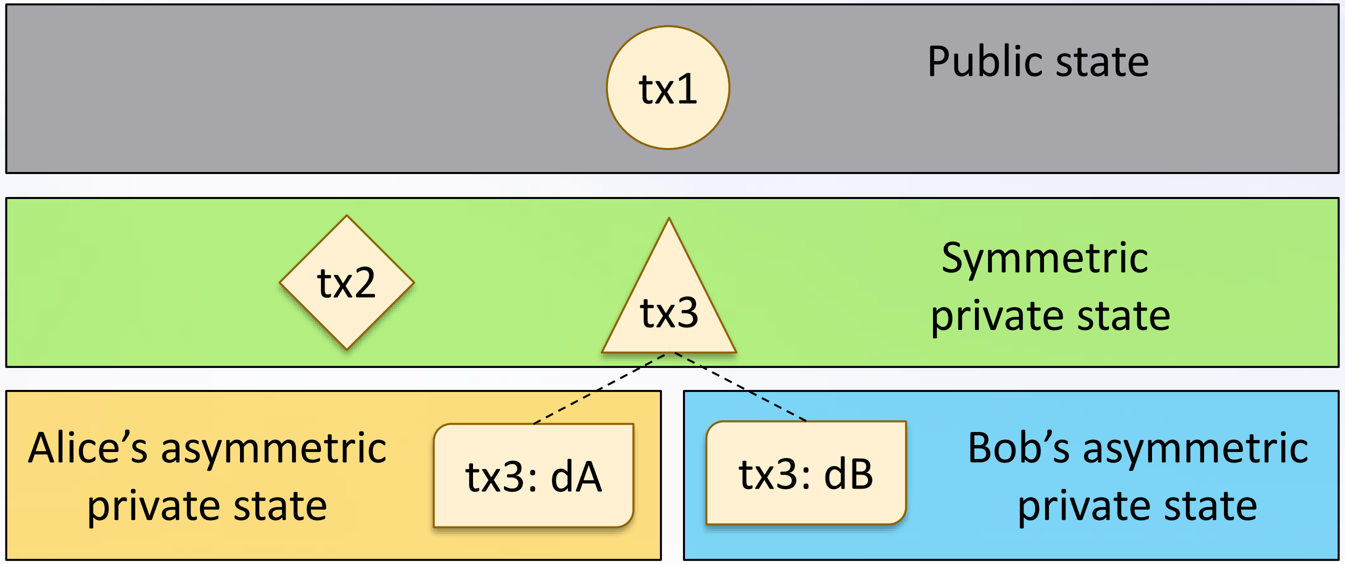
Extended private transaction model for MPC

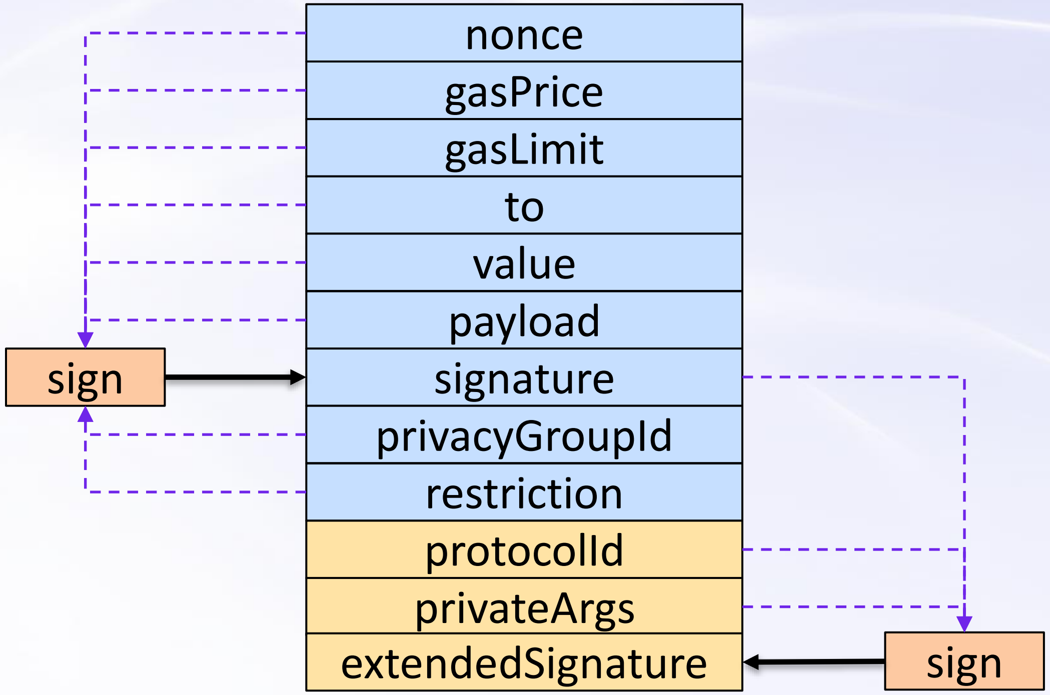
- MPC allows an asymmetric state model
  - Alice and Bob share a privacy group
  - They see the same view for symmetric private transactions
  - They see different data regarding an asymmetric private transaction
    - Reminder: In MPC, x_i is only seen (in plaintext) by the owner P_i



Extended private transaction model for MPC

- Extended private transactions
  - A new type of transaction supporting MPC executions
  - It extends the standard private transaction of Besu
    - **ProtocolId:** specifies which MPC protocol is executed
    - **PrivateArgs:** carries the private data of one user
      - Standard payload is filled with dummy data
    - **ExtendedSignature:** signs extended data
  - **Signature** is publicly verifiable by any node in the blockchain, but **ExtendedSignature** is only verifiable at user's Besu client

Extended private transaction's fields



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Extended private transaction model for MPC

- Interface Smart Contract
  - It exposes the MPC methods to the application using a standard interface
  - Besu translates the contract methods to MPC messages

```
contract PSI {
    constructor(
        address _alice,
        address _bob,
        uint256 _universeLength) public;
    function load(
        uint256[] memory _aliceSet) public
        onlyAlice();
    function consume(
        uint256[] memory _bobSet) public
        onlyBob()
        returns(uint256[] memory);
}
```

```
contract BftRng {
    constructor(
        address[] _participants) public;
    function generate() public
        returns(uint256);
    function commit() public;
    function reveal() public;
    function getRandom() public
        returns(uint256);
}
```

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Extended private transaction model for MPC

- MPC execution
  - Interface Smart Contract ←→ Coordination layer ←→ Cryptographic MPC library
  - **Privacy controller:**
    - Extended to discriminate symmetric private transactions from those asymmetric, based on *protocolID*
    - Creates a new transaction without *privateArgs*, ready for delivery to other nodes
    - Sends the asymmetric private transaction to Tessera
  - PMT is flooded and involved nodes retrieve the private transaction from Tessera
  - **Privacy precompiled contract:**
    - One contract per each Interface Smart Contract
    - Instead of executing the transaction with the execution core (EVM), it coordinates the online execution of the MPC using the cryptographic library

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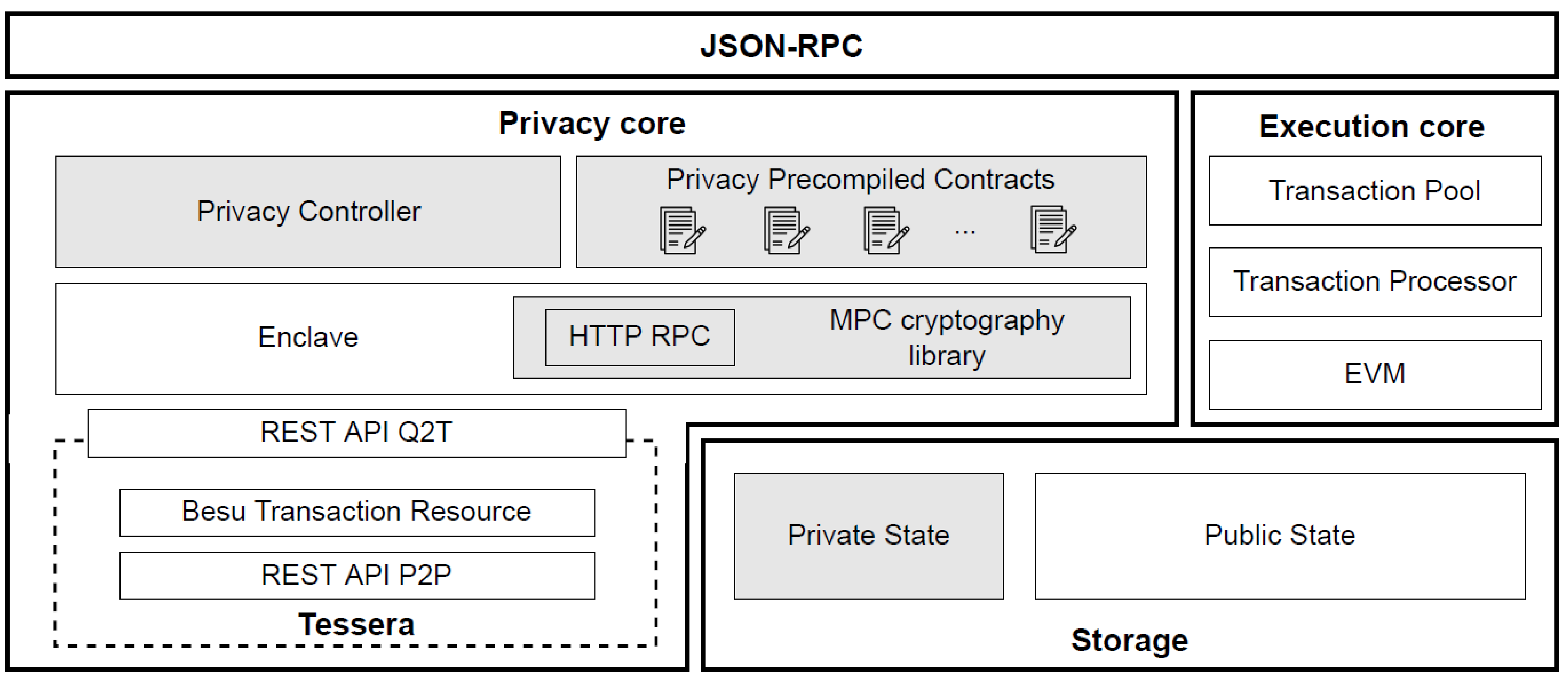
Extended private transaction model for MPC



Extended private transaction model for MPC

- MPC message delivery
  - MPC protocols communicate off-chain
  - Generalize MPC to a tuple of messages $\left((h_1, m_1), \ldots, (h_n, m_n)\right)$
  - Standard Tessera does not understand MPC messages
  - 3 approaches
    - **Modify Tessera:** a new endpoint in Tessera does not store the message hash as identifier, but the header h_i
    - **Whisper protocol in Besu:** sending off-chain secure messages between Besu nodes
    - **Message Delivery Smart Contract:** a Message Delivery precompiled contract supports a message delivery Interface Smart Contract. Each MPC message triggers a new symmetric private transaction delivery, which contract contains the header h_i

Conclusions and future work

- Conclusions
  - Executing MPC protocols from blockchain applications
  - Standard interfaces: Smart contracts
  - Extended transaction model
    - On-chain coordination
    - Off-chain execution
- Future work
  - Add verifiability mechanisms for MPC
  - Dynamic models for MPC (hybrid compilers)
  - Benchmarks to test performance for different MPC protocols

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