Provenance Metadata Management in Distributed Storages Using the Hyperledger Blockchain Platform

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Provenance Metadata (PMD)

- Metadata describing data, provide context and are vital for accurate interpretation and use of data
- One of the most important types of metadata is provenance metadata (PMD)
  - tracking the stages at which data were obtained
  - ensuring their correct storage, reproduction and interpreting
  - ⇒ ensures the correctness of scientific results obtained on the basis of data
- The need for PMD is especially essential when large volume (big) data are jointly processed by several research teams

Types of storages: extremal cases

- Centralized
  - problems:
    - very expensive ⇒ funding ?
    - planning in advance the necessary storage capacity
- P2P-storage with special mechanisms of coding, fragmentation and distribution
  - problems:
    - to ensure a stable pool of resource providers,
    - before such a P2P-based storage can work stably, it requires significant technical, organizational and time costs in the absence of a result guarantee

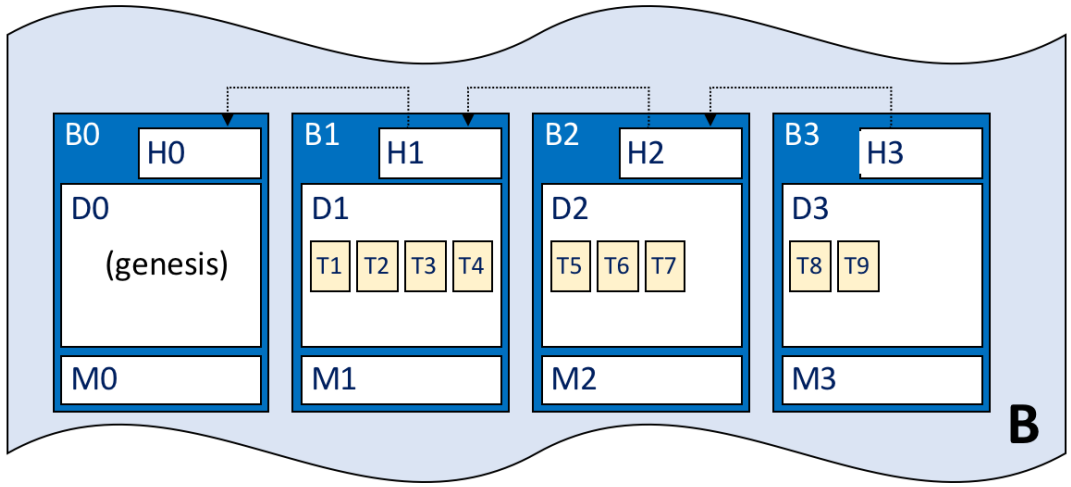
Types of storages: intermediate solution

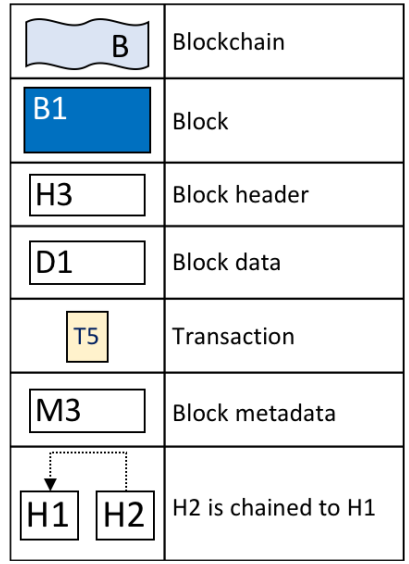
- organizations participating in a large project integrate their local storage resources into a unified distributed pool
- may be particularly advantageous if a project brings together a number of organizationally unrelated participants
- the case corresponds to the baseline usecase being under discussion at this Workshop
- ⇒ dynamically changing distributed environment

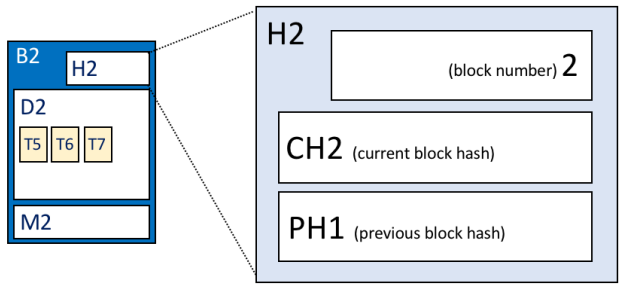
PMD MS Construction: Distributed Solution

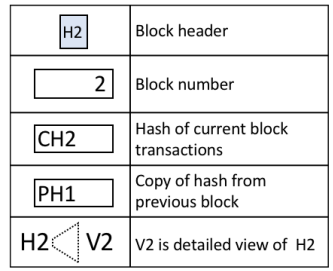
- distributed environment ⇒ distributed registry for PMD
- we suggested to use the blockchain technology which provides
  - that no records were inserted into the registry in hindsight
  - no entries were changed in the registry
  - the registry has never been damaged or branched
  - monitoring and restoring the complete history of data processing and analysis

Blockchain structure









PMD MS Construction: Which Blockchain (1/2)

- type of the blockchains
  - permissionless blockchains, in which there are no restrictions on the transaction handlers
  - permissioned blockchains, in which transaction processing is performed by specified entities
- permissionless:
  - algorithms are based on
    - Proof-of-Work – highly resource-consuming, probability of reaching a consensus, which grows with time elapsing, ...
    - Proof-of-Stake – Nothing-at-Stake problem,…
  - suitable for open (public) networks of participants (Bitcoin, etc.)

PMD Projects Based on Permissionless Blockchains

- ProvChain, SmartProvenance: intended for a cloud storage
  - no DDS, no different administrative domains, no real consensus among the potentially conflicting parties
- Storj, Sia: intended for a P2P network of public storage resources
  - public blockchain - mainly for providing mutual settlements between suppliers and consumers of (P2P) resources
  - very restricted PMD facilities

PMD MS Construction: Which Blockchain (2/2)

- Permissioned:
  - there is a fixed number of trusted transaction/blockchain handlers
  - the handlers must come to a consensus about the content and the order of the recorded transactions
    - distributed consensus algorithm should be involved
  - form a more controlled and predictable environment than permissionless blockchains
  - suitable for networks with naturally existing trusted parties
    - our case: storage providers, representatives of real organizations participating in the project,...

System state

- The state of the entire distributed storage = aggregated state of the set of files stored in it with their states at the moment
- The state of a data file is determined by PMD:
  - global ID + attributes, including:
    - local file name in a storage: fileName;
    - storage identifier: storageID;
    - creator identifier: creatorID;
    - owner identifier: ownerID
    - type: type=primary/secondary/replica
    - …

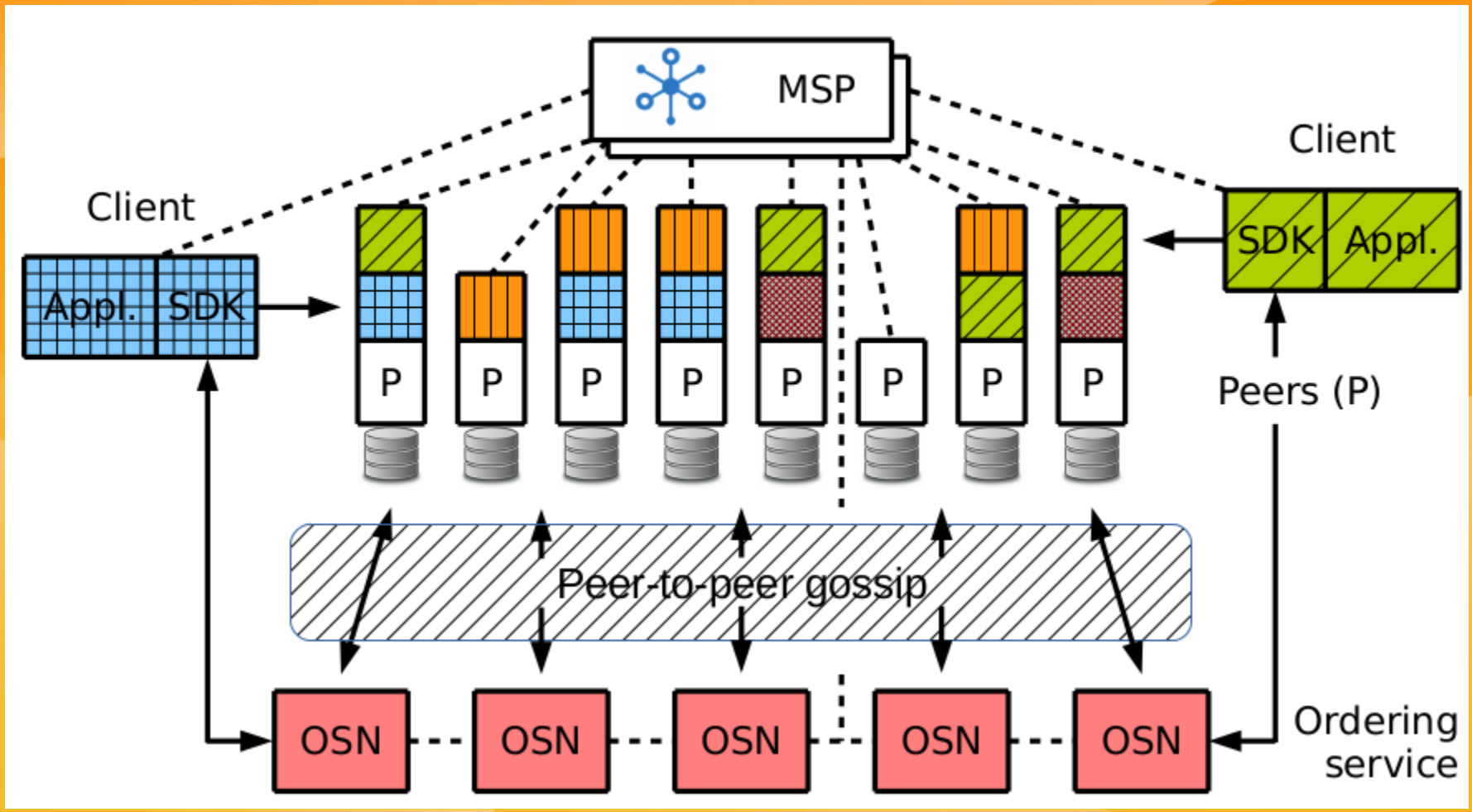
Basic operations ⇒ transactions

- new file upload
- file download
- file deletion
- file copy
- copying a file to another repository
- transferring a file to another repository
  - each active transaction ⇒ update of some state attributes
    - for example, after the transaction "file download" the values of the keys change: "number of file downloads" and "users who downloaded the file".

HyperLedger Fabric (1/2)

- Analysis of existing platforms shows that the formulated problems most naturally can be solved on the basis of the
  - Hyperledger Fabric blockchain platform (HLF; www.hyperledger.org)
  - together with Hyperledger Composer (HLC; hyperledger.github.io/composer) = set of tools for simplified use of blockchains
- permissioned blockchains
  - transactions are processed by a certain list of trusted network members

HyperLedger Fabric (2/2)



From: *E. Androulaki et al. "Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains," in Proc 13th EuroSys Conf. 2018*

Business process within (HLF&C)-platform

- **Assets** are tangible or intellectual resources, records of which are kept in registers
  - in our case, the assets are data files; their properties (attributes) are provenance metadata
- **Participants** are members of the business network.
  - they can own assets and make transaction requests
  - can have any properties if necessary
- **Transaction** is the mechanism of interaction of participants with assets
- **Events:** messages can be sent by transaction processors to inform external components of changes in the blockchain

HyperLedger Fabric → ProvHL (1/4)

- ProvHL = Provenance HyperLedger
- operation of smart contracts (chaincodes)
  - adaptation of HLF for the business process of sharing storage resources
- provides a record of transactions & advanced query tools
- advanced means for managing access rights
  - access rights can be managed by network members within their competence

HyperLedger Fabric → ProvHL (2/4)

- Participants
  - Person
  - StorageProvider
- Assets
  - File
  - Storage
  - Operation
  - Group
- Transactions
  - FileAccessGrant
  - FileAccessRevoke
  - OperationUploadCreate
  - OperationUploadSetState
  - ...

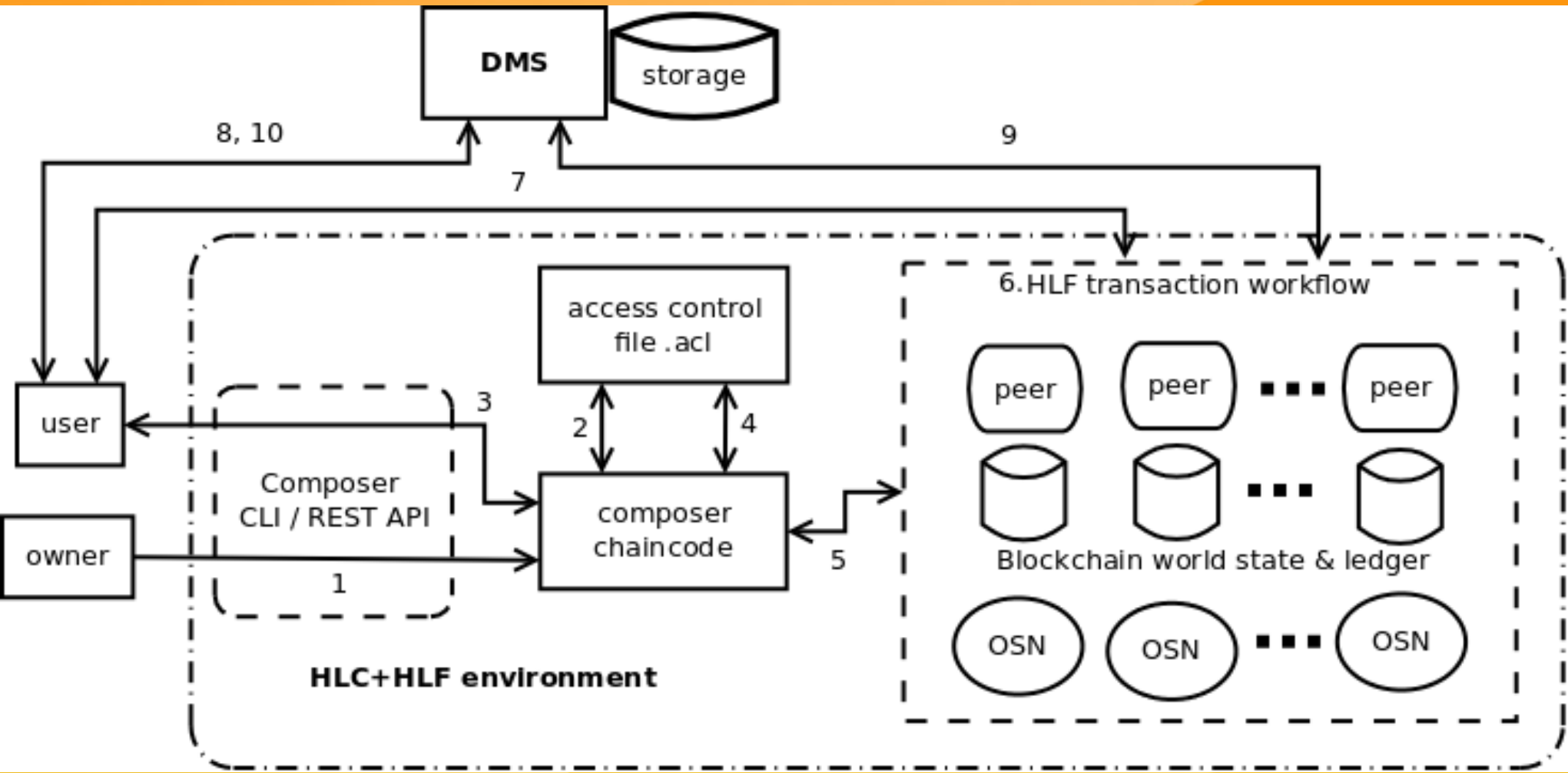
ProvHL operation (3/4)

- Operations with files comprise of at least two types of transactions recorded in the blockchain:
  - client requests,
  - server responses
- Operation states: ***`STARTED, COMPLETED, ERROR,`*** *…*
- Operation = asset ⇒
  - level of correspondence (history recorded in blockchain) ⇔ (real history of the data in the distributed storage) practically acceptable
  - delegation of rights: user/service → service
  - ...

HyperLedger Fabric → ProvHL (4/4)

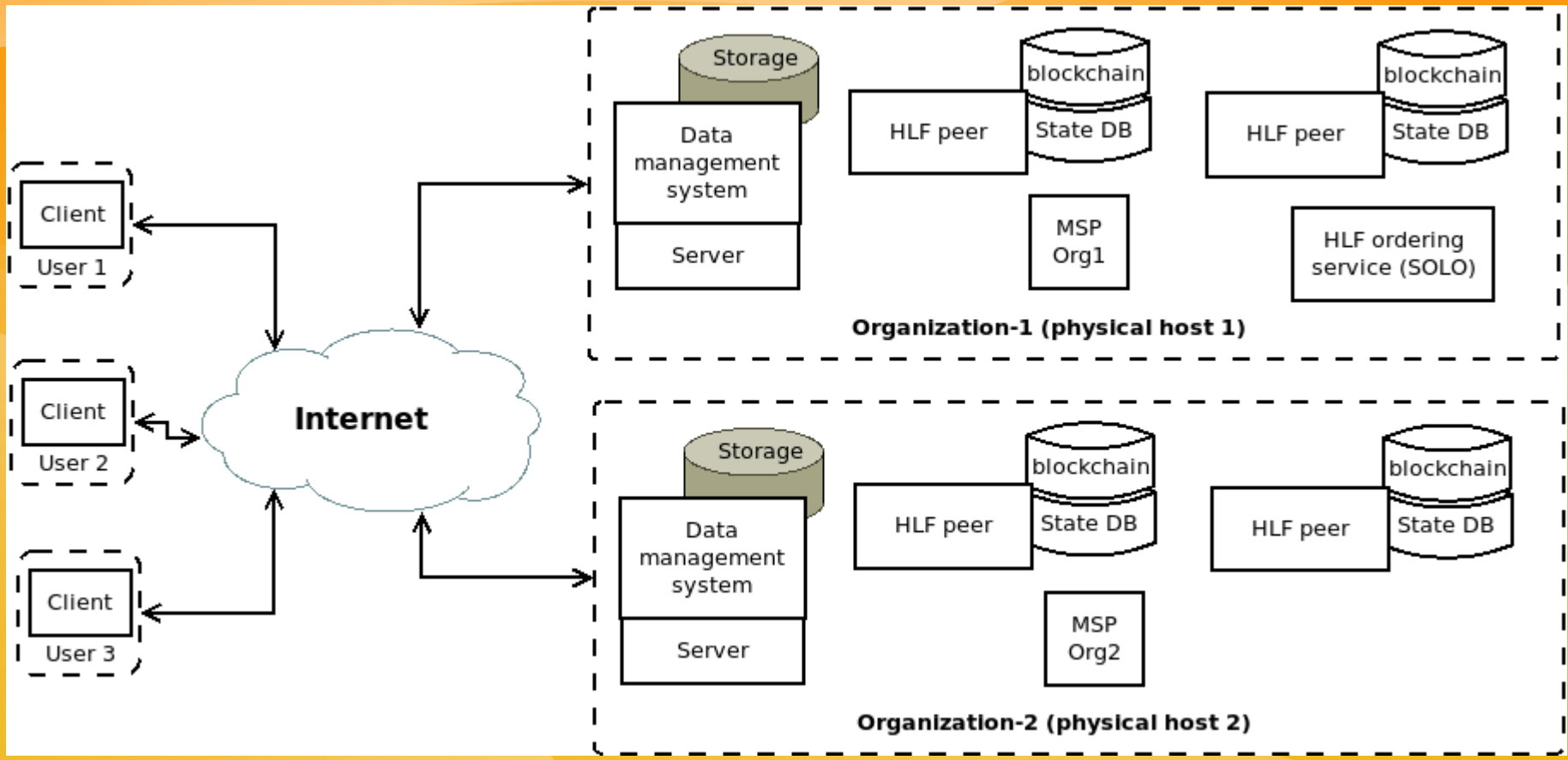
- thanks to its modular structure, it allows using different algorithms to reach consensus between business process participants
- has a developed built-in security system based on PKI

ProvHL operation



Simplified scheme for recording transactions with provenance metadata and managing data access rights based on HLF&C

ProvHL Testbed (2/2)



Conclusion

- The new approach to managing PMD and data access rights in distributed storage has been developed