Enhancing Blockchain Interoperability through Sidechain Integration and Valid-Time-Key Data Access Control

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Abstract. Nowadays, in the realm of blockchain technology, a pressing challenge lies in the current lack of interoperability, which significantly limits its potential for innovation and advancement. However, the attainment of cross-chain interoperability is undeniable of utmost importance, as it holds the key to maximizing the network's computing performance, expanding storage capacity, and unlocking unparalleled scalability. Therefore, this research introduces a groundbreaking cross-chain architecture that tackles the challenge of interoperability and sharing capabilities, together with surpassing the limitations posed by previous interchain interaction systems. In the proposed system, interchain data transfer is revolutionized through the utilization of a Sidechain that incorporates a valid-time key (VTK) data access control scheme for the purpose of empowering the verification of blockchain data across multiple blockchain networks. In the realm of healthcare data exchange, our experiments unequivocally showcase the effectiveness of the proposed architecture in enabling seamless interchain communication and secure data transfer while ensuring the security and authenticity of the transferred information. Through the implementation of the VTK mechanism, our system establishes a robust defense against unauthorized access and fraudulent activities by tightly controlling access privileges, ensuring that only authorized parties are granted access within specified time limits.

Keywords: Access control · Blockchain interoperability · Cross-chain · Sidechain · Valid Time Key.

1 Introduction

Blockchain has gained extensive applications across a range of industries such as finance, insurance, healthcare, social support, and education [1]. However, research suggests that the issue of interoperability among diverse blockchains can give rise to challenges. Currently, within the domain of blockchain applications, collaboration among multiple entities within the same network is commonplace. However, for the technology to progress further, fostering interoperability between disparate chains is a crucial aspect [2]–[4]. In the healthcare sector, effective transparency is a cornerstone of success, enabling seamless interactions among parties. However, the fragmented storage of data in existing blockchain systems poses a challenge when it comes to sharing information among stakeholders, primarily due to discrepancies in storage and control system designs [5]. This fragmented and centralized information gives rise to notable information concerns, imposing significant limitations on the provision of data accuracy and high-quality patient care and treatment.

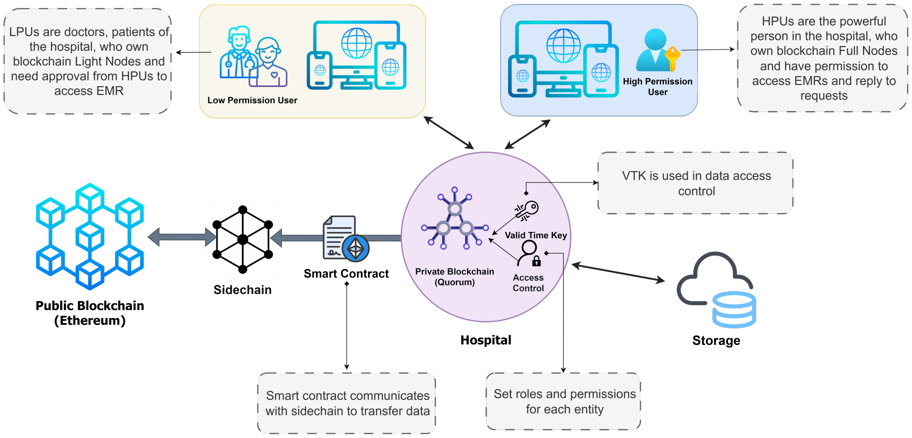
LPUs are doctors, patients of the hospital, who own blockchain Light Nodes and need approval from HPUs to access EMR
Low Permission User
High Permission User
HPUs are the powerful person in the hospital, who own blockchain Full Nodes and have permission to access EMRs and reply to requests
VTK is used in data access control
Valid Time Key
Private Blockchain (Quorum)
Access Control
Hospital
Public Blockchain (Ethereum)
Sidechain
Smart Contract
Storage
Smart contract communicates with sidechain to transfer data
Set roles and permissions for each entity

Fig. 1: The concept of cross-chain communication architecture in Healthcare

In the healthcare industry, centralized information management in healthcare faces considerable risks due to its high vulnerability to cyber attacks, resulting in the potential loss or theft of data [6], [7]. To facilitate the effective management and enhance patient care processes in healthcare facilities, the implementation of an interoperability mechanism is essential while ensuring robust security measures for the exchange of patient medical records [8]. Building and optimizing a cross-chain interaction support system for information verification is of utmost importance; nonetheless, current solutions present obstacles due to their high costs and intricate implementation processes.

To overcome the obstacle of transferring data between separate blockchains, our proposal introduces a sidechain of Oracle nodes. The sidechain serves as a communication bridge between two chains while ensuring data validity through verification by other nodes. Enforcing access control through VTK, our system ensures that data transfer and viewing are strictly limited to authorized parties only. With an unwavering focus on data security and privacy, our solution makes significant contributions in the following aspects:

– We propose a novel approach introducing an innovative interchain system that leverages the sidechain architecture to verify data transparency, incorporating access control through the implementation of the VTK mechanism.
– Our system was successfully implemented and tested on a network of blockchain platforms, resulting in fast and secure interchain mobility and data sharing. Performance, cost, and security were evaluated, with mostly positive results.

2 Related Works

In the pursuit of cross-chain interoperability and seamless execution of smart contracts across multiple networks, the adoption of standardized protocols and the application of innovative approaches emerge as pivotal factors. By embracing these remarkable advancements, the boundless potential of blockchain technology is unlocked, giving rise to an interconnected and collaborative ecosystem. [9], [10] and Buterin [11] have shed light on the importance of blockchain interoperability in their notable studies, with three primary categories of strategies: notary schemes, hash-locking, and relays/sidechain as essential frameworks for achieving seamless connectivity across diverse blockchain networks.

Notary Schemes: The notary scheme in the cross-chain approach offers a relatively simple solution. As elucidated by [12], this mechanism involves a trustworthy set of entities, acting as intermediaries, initiating actions in one blockchain in response to events taking place in another blockchain. Interledger[3] stands as a prominent and influential project in the realm of notary mechanisms. This protocol streamlines currency transfers between ledgers by leveraging a third-party connector, akin to the role of a notary in blockchain interoperability. However, reliance on a specific third party in notary technology can raise valid concerns regarding centralization, bottleneck, or blind trust.

Hash-locking: The utilization of hash locking as a cross-chain mechanism offers a streamlined approach to asset exchange removing the reliance on third-party involvement [13], [14]. In this process, both parties lock their exchangeable assets within the smart contract and send the hash value of a selected secret key to the recipient. The successful execution of the transaction relies on meeting the predetermined hash conditions within a specified timeframe. In the event that these requirements are not fulfilled, the assets are promptly returned to their rightful owners, ensuring a safeguarded process. While hash-locking serves as a viable solution for cross-chain asset exchange and transfer, it necessitates the compatibility of both involved chains to support the same hash function. This requirement can pose limitations in situations where the participating chains utilize distinct hashing algorithms or possess disparate technical prerequisites. Furthermore, a significant challenge lies in the high cost and intricate design requirements involved in ensuring mutual understanding and compatibility of smart contracts across different blockchains.

Relays/sidechain: is a promising cross-chain solution that places a premium on scalability and interoperability, offering a decentralized alternative

[3] https://interledger.org/

compared to notary schemes. By leveraging this mechanism, the transfer of digital property, including assets, tokens, and data, becomes effortless and fluid across disparate blockchain networks. Within the blockchain ecosystem, acting as an autonomous secondary blockchain, a sidechain operates independently, safeguarding the performance and security of the main blockchain without any adverse impact. Prominent blockchain interoperability platforms like Cosmos [15] and Polkadot [16] exemplify this concept by implementing an intermediary chain that fosters seamless and efficient cross-chain interactions.

The captivating realm of blockchain technology in the healthcare sector has drawn considerable interest from researchers, with a specific emphasis on its application in managing electronic medical records (EMRs) [17]. Unlocking the potential of blockchain technology, electronic medical records (EMRs) can find a safe sanctuary for storage, access, and sharing among authorized participants, preserving the utmost integrity and privacy of healthcare data. Nonetheless, when developing blockchain-based solutions, it is paramount to conduct a meticulous consideration of trade-offs, specifically with regard to security and interoperability.

3 Proposed System

Immersed in the environment of a hospital, the proposed system takes center stage as it empowers efficient management of patient health records through a robust and confidential blockchain network. However, the thing is the construction of such a network with multiple full nodes, responsible for preserving the complete blockchain history and verifying both transactions and new blocks, can often incur significant expenses that may be deemed prohibitive. Conversely, a network that predominantly features only a limited number of full nodes and numerous light nodes optimized for rapid transactions and daily activities can raise potential concerns regarding the integrity and confidentiality of stored electronic medical records (EMRs). In order to address this challenge, it becomes vital to establish verifiable evidence of data integrity, which can be securely stored on the public blockchain for the purpose of not only enhancing security but also enabling effortless retrieval of information when needed. Overcoming the obstacle of transferring data between blockchains with distinct architectures poses a significant challenge. To tackle this issue, our proposed solution, depicted in Figure 1, presents a comprehensive resolution, which will be elaborated upon in subsequent sections, providing an in-depth analysis of the system components in the subsequent sections. Table 1 presents a comprehensive list of the acronyms with a view to facilitating comprehension throughout the article.

3.1 Blockchain

To exemplify distinct blockchain architecture communication, our cross-chain model integrates Quorum[4] for the PriBC network and Ethereum for the PuBC network.

[4] https://consensys.net/quorum/

Table 1: Abbreviations and Acronyms

Abbreviation/Acronym	Definition
PuBC	Public blockchain
PriBC	Private blockchain
EMR	Electronic Medical Record
VTK	Valid Time Key
EID	EMR ID
UID	User ID
LPU	Low-Permission User
HPU	High-Permission User
LN	Light Node
FN	Full Node

1. Private Blockchain Network: To fortify data security and streamline the process of data access requests, we implemented access controls using smart contracts on the Quorum blockchain. Within our private blockchain entities, three fundamental roles have been established:
   - Doctors, medical staff, and associated patients, being classified as LPUs, have the capability to request EMRs if granted access by full nodes.
   - Deans and managers, as prominent users within the system, hold pivotal roles and possess substantial permissions in validating EMRs, accessing content, and granting permissions to LPUs as needed.
   - Admins hold the utmost authority, taking on the pivotal responsibility of system management and addressing any emergent situations.
2. Public blockchain network: Upon successful validation of an EMR by the FNs, the subsequent crucial step involves encryption of the EMR before it is securely stored in either cloud storage or the InterPlanetary File System (IPFS). Simultaneously, a unique hash value is generated through the process of hashing. The Ethereum blockchain acts as a secure repository for storing the hash value which is accompanied by the EMR's ID as a distinctive tag. The significance of these pieces of information cannot be denied, as they serve as compelling evidence during the validation process of the EMR. Moreover, upon requirement, the retrieval of the hash from Ethereum is seamless and hassle-free, further enhancing the overall efficiency and reliability of the system.

3.2 Sidechain

A sidechain is an innovative distributed network that empowers the validation and efficient transfer of data between two interconnected and diverse blockchains, commonly referred to as heterogeneous blockchains. The sidechain serves as a dynamic pathway, orchestrating the smooth transmission of hashes in reverse between the PriBC and PuBC networks, establishing a harmonious bridge for efficient communication and interoperability. Our proposed system incorporates a decentralized oracle network as the sidechain, facilitating the retrieval of external data into the blockchain and enabling the seamless transmission of internal blockchain data to the external realm. In the system, the oracle assumes a pivotal role with a multitude of responsibilities including receiving data requests from users, empowering the oracle contract to seamlessly transmit data outside the blockchain, and facilitating the provision of data to interconnected blockchains. In Figure 2, a captivating visualization depicts the dynamic interaction between two distinct blockchains and an oracle.

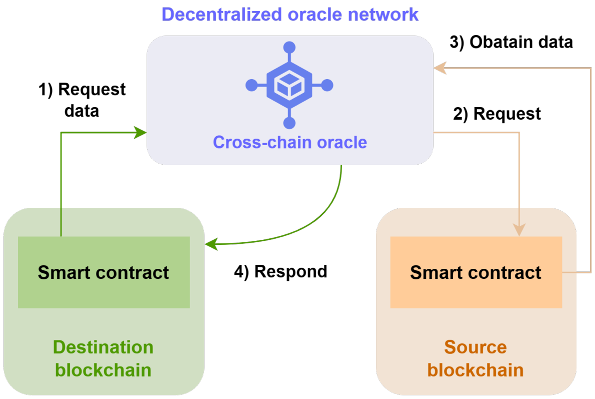

Fig. 2: The cross-chain interaction between two heterogeneous blockchains

Within the sidechain realm, the indispensable role of each oracle comes to the fore as they fulfill user DApp requests and facilitate the seamless transfer of data between the interconnected blockchains. By leveraging smart contracts for interaction with the source blockchain, our system seamlessly facilitates on-demand data collection, including the retrieval of either newly generated hashes following the EMR hash or previously saved hashes linked to specific EMR IDs. When the data aligns with the new hash, a seamless transfer takes place, securely storing it on Ethereum, where it is uniquely identified by the EMR ID. Moreover, the successful execution of this operation hinges upon the presence of a crucial Ethereum smart contract, which assumes a pivotal role in the process. The comprehensive explanation of the process for querying the stored hash to perform integrity checks will be elaborated upon in section 3.4.

3.3 Valid Time Key - VTK

In scenarios where LPUs seek access to encrypted data stored in the database, the utilization of a VTK becomes important in providing them with the required access privileges. During the process where a LN initiates a request to FNs, the content undergoes decryption by HPUs with a private key, contingent upon their approval. Following that, a connection is established, paving the way for the creation of a novel VTK, which is dispatched to the DApp of the LN that initiated the initial request. Armed with this valid time key, the DApp effortlessly establishes a secure connection, unveiling the gateway to access and comprehend

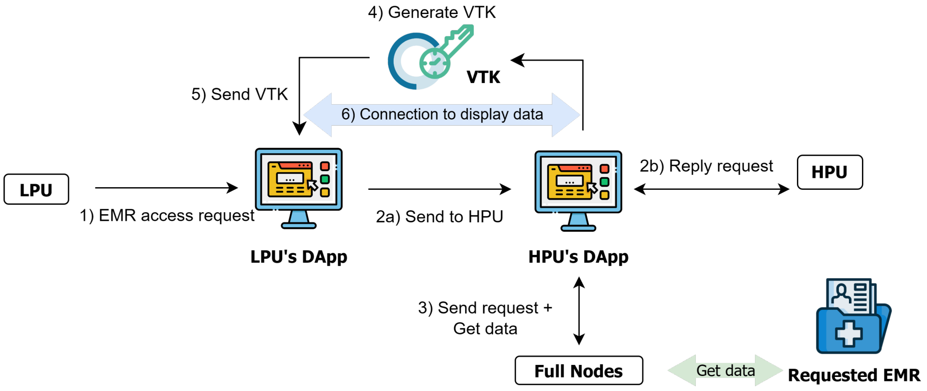

Fig. 3: The data-access request process.

the content of the data. Upon the expiration of the designated time, the validity of the time key ceases, triggering an instantaneous termination of the connection by the full nodes. As a consequence, the light nodes are effectively barred from accessing any information. Figure 3 showcases a detailed process model and Algorithm 1 offers a concise depiction of an EMR access control transaction using VTK.

Algorithm 1 EMR access control procedure

```
EMRAccessRequest ← $EID$                                          ▷ Step 1
if getApprovalFromHPU ← $UID$ then                                ▷ Step 2
    $decryptedEMR$ ← DecryptData($PrivateKey, EID$)               ▷ Step 3
    $VTK$ ← Generation                                            ▷ Step 4
    $dataConnection$ ← EstablishConnection ← $VTK, decryptedEMR$
    Send $VTK$ to LPU                                             ▷ Step 5
    while VTK is valid do
        $dataConnection$ ← $VTK$                                  ▷ Step 6
    end while
    Close $dataConnection$
else
    NotifyClient(”Don’t get approval”);
end if
```

3.4 Cross-chain data transfer

In this section, we delve into the elucidation of the transfer process for stored hash data from the public blockchain to the PriBC, which is vividly depicted in Figure 4. EMRs undergo encryption and storage safeguarded by the secure custody of the private key lying in the hands of FNs. As a user initiates a request for hash verification of an EMR's integrity through the DApp, this meticulous process safeguards the utmost security of sensitive medical data and empowers authorized individuals to validate the authenticity of the EMR. Algorithm 2 offers a captivating insight into the sequential operations involved in the processing of EMR requests.

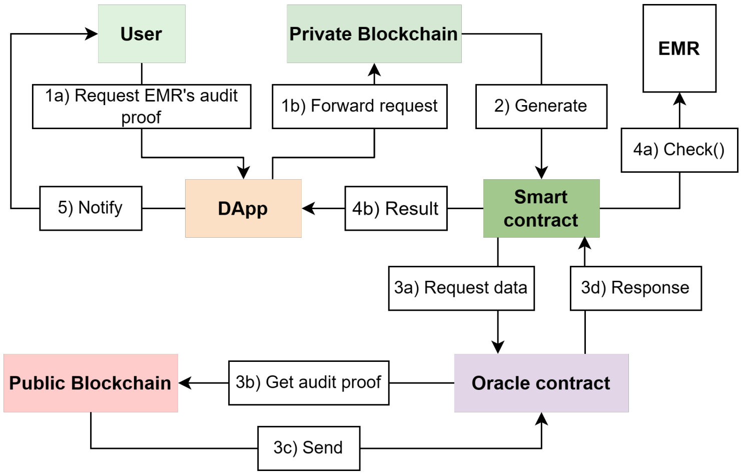

Fig. 4: The cross-chain data transfer process.

Step 1) EMR audit-proof, including hash and ID tag, is requested by clients from PuBC via DApp, which forwards the request to PriBC for processing. **Step 2)** The PriBC creates a smart contract and an oracle contract to communicate with the sidechain and retrieve data from the target blockchain. **Step 3)** The sidechain retrieves the requested data and transfers it to the PriBC. **Step 4)** The PriBC undertakes an integrity verification of the EMR by leveraging the hash value retrieved from the PuBC. **Step 5)** Ultimately, The DApp notifies the client of the results.

4 Experiments and Results

4.1 Performance Evaluation

Throughout the experimental phase, we utilized three VMs, each equipped with a 4-core CPU, and a 60GB hard drive, 16GB of memory and operated on the Ubuntu 22.04 operating system. To assess the system's functionality, we undertook a series of activities encompassing the registration of a DApp account, initiation of access requests for Electronic Medical Records (EMRs) via the DApp, prompt authorization of requested EMR access utilizing VTK, and subsequent connection revocation after the designated timeout period. For performance evaluation, we meticulously track the duration of these transactions, as illustrated in Figure 5, and conduct multiple measurements for each transaction to ensure utmost accuracy and reliability. Through the meticulous analysis of experimental

Algorithm 2 Verify the integrity of the EMR

```
Input: ID of the requested EMR
Output: Unmodified or Modified
Perform integrity verification of the EMR request            ▷ Step 1
create Oracle contract                                       ▷ Step 2
create PriBC smart contract
if isExistsInPuBC(ID) then                                   ▷ Step 3
    $AuditProof \leftarrow$ Fetch
    Oracle node transfers $AuditProof$ to PriBC
else
    The transaction is canceled
    Exit
end if
$calHash \leftarrow hashCalculation \leftarrow EMR$           ▷ Step 4
$retrievedHash \leftarrow AuditProof$
if $calHash == retrievedHash$ then
    return Unmodified
else
    return Modified
end if
NotifyClient                                                 ▷ Step 5
```

results, we conducted a comprehensive assessment of the transaction performance pertaining to the storage and data access control of EMRs, enabling us to gain valuable insights into the efficiency and effectiveness of these processes. When it comes to account registration on the DApp, it entails a multi-step process involving transaction creation on PriBC, identity verification, and authorization, which usually results in slightly extended processing times compared to the aforementioned transactions. However, the overall results present an exceptionally positive outlook, solidifying the notion of a highly favorable outcome. In the context of query transactions involving cross-chain interactions, the measurement captures the entire timeline, starting from the moment the user submits the request until the eventual receipt of the integrity check result, offering valuable insights into the efficiency and effectiveness of cross-chain communication. Our thorough evaluation confirms that our proposed solution has yielded positive outcomes and holds promising potential for future advancements.

Additionally, we meticulously evaluate the cost analysis of the system based on the average value of multiple transactions. Table 2 presents the calculated results and the transaction fees for each transaction, measured in gas units. The transaction fee for each transaction is measured in gas unit, and the calculation results are shown in Table 2. The gas consumption for registering transactions for each entity remains consistently equivalent on average, requiring only a one-time execution. The cost linked to storage, data access, and cross-chain transfer is tied to the complexity of deployment and transmission. We go under the assumption that the incurred cost is not only reasonable but also falls within the realm of acceptability. Additionally, Table 2 provides insights into the CPU

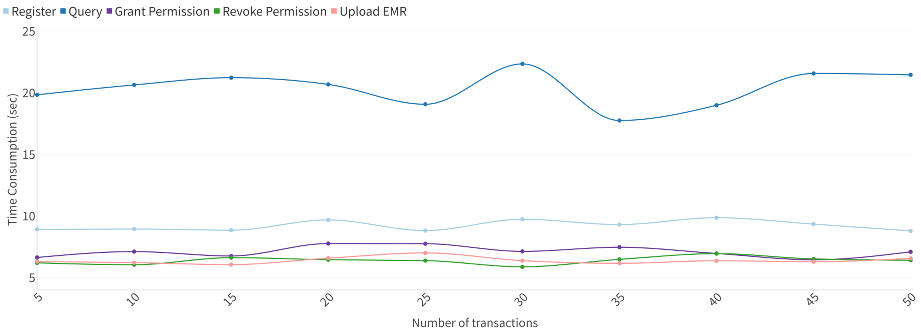

Fig. 5: The comparison of time consumption across five types of transactions

usage associated with each transaction. When analyzing the various processes, it becomes evident that the query transaction stands out as the most demanding in terms of the highest CPU usage, accounting for an imposing 76.31%. Due to the inherent constraints of our virtual machine's functionality, it is noteworthy that the resulting CPU usage percentage may appear relatively substantial. However, this value remains well within acceptable limits, with the potential for significant improvement through an upgrade to the hardware configuration. Currently, the implementation of our smart contracts is readily accessible online on GitHub[5].

Table 2: The average cost and CPU usage of transactions

Object	**Transaction**	**CPU usage**	**Gas**	**USD**
Blockchain Entities	Register Manager	66.29%	46407	4.46
	Register Doctor	66.17%	46378	4.45
	Register Patient	66.12%	46378	4.45
EMR	Store data	62.22%	92664	8.90
Data access control	Grant Permission	66.82%	161275	15.48
	Revoke Permission	66.60%	30261	2.91
Audit proof	Query	76.31%	229851	22.07

4.2 Security Analysis

In our pursuit of optimal performance and uncompromised security for the blockchain networks, our sidechain operates as a decentralized Oracle network, functioning independently to ensure the proposed solution does not influence that pursuit. Within this system, the responsibility of managing each transaction lies with an Oracle node, while the other nodes act as verifiers to uphold transparency and deter any fraudulent activities. For the utmost security of transferred information during the transfer process, we employ robust encryption techniques that preserve privacy and uphold confidentiality, even against man-in-the-middle attacks. In order to establish a robust access control, our system

[5] https://github.com/Bingtoni2122/Sidechain-Integration-and-Valid-Time-Key

adopts a role-based framework that assigns specific permissions to different entities. By implementing this role division, data verification requests are restricted solely to the HPU to minimize the possibility of denial of service attacks. The utilization of VTK brings forth a remarkable solution, providing clients with secure and convenient access to data while safeguarding data privacy through time-limited permissions. To safeguard against authenticity attacks, the registration of a new account undergoes a consensus-based validation process from HPUs within the PriBC network, effectively preventing external attackers from unauthorized access or engaging in fraudulent activities. Within our network, a fundamental requirement is every account needs to undergo registration ensuring a comprehensive mapping of verification, identity, and role-related information. When clients attempt to log in, our system validates all provided information, granting access solely to accounts that meet the necessary qualifications.

5 Conclusions and Future Work

In this paper, we introduce a captivating blockchain interoperability solution that leverages the power of sidechain and Valid Time Key (VTK). Our sidechain, operating as a decentralized network, plays a pivotal role as a trusted intermediary, forging seamless connections to a multitude of heterogeneous blockchains. Additionally, we present a groundbreaking concept known as VTK to enhance secure data access management and convenience. The experimental results affirm the outstanding performance of our system in terms of remarkable functionality and seamless cross-blockchain interaction. In future work, we are committed to enhancing system performance, optimizing costs, and undertaking extensive testing o unlock the full potential of incorporating external blockchain data. Furthermore, we recognize the importance of addressing mutable data scenarios and embarking on the exploration of alternative methods for hash functions that can effectively verify the integrity of such data while compatible with blockchain.

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