



International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 19 No. 4 (2023)



ijerst.editor@gmail.com
editor@ijerst.com

A SCALABLE BLOCKCHAIN FRAMEWORK FOR PRIVACY-PRESERVING PERSONAL DATA SHARING AND ACCESS CONTROL

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ABSTRACT

The rapid growth of digital services, cloud computing, Internet of Things (IoT) devices, and online platforms has resulted in an unprecedented volume of personal data being generated, stored, and exchanged across distributed environments. While data sharing facilitates innovation and service personalization, it also raises significant concerns regarding privacy, security, unauthorized access, and data misuse. Conventional centralized data management systems often suffer from single points of failure, limited transparency, and vulnerability to cyberattacks, making them inadequate for protecting sensitive personal information in modern digital ecosystems.

This paper proposes a Scalable Blockchain Framework for Privacy-Preserving Personal Data Sharing and Access Control that leverages the decentralized and immutable nature of blockchain technology to enhance data security, transparency, and user control. The proposed framework integrates blockchain-based distributed ledgers with fine-grained access control mechanisms and cryptographic techniques to ensure secure and privacy-aware data sharing among authorized entities. Smart contracts are utilized to automate access authorization, policy enforcement, and auditability, thereby eliminating reliance on centralized intermediaries and improving trust among participants.

To address scalability challenges commonly associated with blockchain networks, the framework incorporates lightweight consensus mechanisms, off-chain storage solutions, and efficient data indexing strategies that reduce computational overhead and transaction latency.

Furthermore, advanced encryption and privacy-preserving protocols are employed to safeguard sensitive user information while enabling controlled access based on predefined permissions and user-defined policies. The architecture supports dynamic access management, secure data ownership verification, and transparent tracking of data-sharing activities.

Experimental evaluation demonstrates that the proposed framework achieves improved scalability, reduced access latency, enhanced security, and stronger privacy protection compared with traditional centralized and existing blockchain-based data-sharing approaches. The results indicate that the framework effectively balances security, privacy, and performance requirements, making it suitable for healthcare, smart cities, financial services, IoT ecosystems, and other data-intensive applications requiring secure personal data management.

Keywords: Blockchain, Personal Data Sharing, Privacy Preservation, Access Control, Smart Contracts, Data Security, Decentralized Systems, Cryptography, Scalable Architecture, Distributed Ledger Technology.

I. INTRODUCTION

The exponential growth of digital technologies, cloud services, Internet of Things (IoT) devices, and online platforms has resulted in the generation of massive volumes of personal data. Individuals routinely share sensitive information such as medical records, financial transactions, location data, and social interactions across multiple digital ecosystems. While data sharing enables personalized services, collaborative analytics, and improved decision-making, it also raises significant concerns regarding privacy,

security, ownership, and unauthorized access to personal information [1]. Traditional centralized data management systems often rely on trusted third parties for data storage and access control, creating challenges such as single points of failure, data breaches, lack of transparency, and limited user control over personal information [2].

Recent years have witnessed increasing incidents of cyberattacks and large-scale data leaks, highlighting the limitations of conventional access control mechanisms. Organizations storing vast amounts of sensitive information remain attractive targets for malicious actors, resulting in substantial financial losses and privacy violations [3]. Furthermore, centralized architectures often suffer from interoperability issues, making secure data exchange among multiple stakeholders difficult. As digital ecosystems continue to expand, there is a growing demand for decentralized solutions that can provide secure, transparent, and trustworthy personal data sharing mechanisms while preserving user privacy [4].

Blockchain technology has emerged as a promising solution to address these challenges. As a decentralized and immutable distributed ledger, blockchain enables transparent and tamper-resistant recording of transactions without requiring a central authority [5]. Through cryptographic mechanisms, consensus protocols, and distributed trust models, blockchain enhances data integrity, auditability, and accountability. These characteristics make blockchain particularly suitable for applications involving sensitive data sharing, identity management, healthcare systems, financial services, and smart city infrastructures [6].

Despite its advantages, blockchain adoption for personal data sharing introduces several privacy concerns. Public visibility of transaction records, metadata exposure, and the permanent nature of stored information may potentially reveal sensitive user details if appropriate privacy-

preserving mechanisms are not implemented [7]. Consequently, researchers have proposed various techniques, including encryption schemes, attribute-based access control, zero-knowledge proofs, and smart contract-based authorization models, to ensure that only authorized entities can access specific data resources while maintaining confidentiality and compliance with privacy regulations [8].

Fine-grained access control has become an essential requirement in modern data-sharing environments. Unlike traditional role-based approaches, fine-grained mechanisms enable data owners to define detailed access policies based on attributes, contexts, and user privileges. Such flexibility allows individuals to retain greater control over their personal information and dynamically manage permissions according to evolving requirements [9]. When integrated with blockchain technology, fine-grained access control can provide transparent authorization, immutable audit trails, and decentralized trust management, thereby improving both security and privacy.

Another critical challenge in blockchain-based systems is scalability. As the number of users and transactions increases, blockchain networks may experience performance bottlenecks, increased latency, and higher storage requirements. To address these limitations, researchers have explored scalable architectures incorporating off-chain storage solutions, lightweight consensus protocols, distributed indexing techniques, and hybrid blockchain frameworks. These approaches aim to maintain the security and transparency benefits of blockchain while supporting efficient large-scale data sharing applications [10].

Motivated by these challenges, this study proposes a ****Scalable Blockchain Framework for Privacy-Preserving Personal Data Sharing and Access Control****. The proposed framework integrates blockchain technology, cryptographic protection mechanisms, smart contracts, and fine-

grained access control policies to enable secure and efficient personal data management. By combining decentralization, privacy preservation, and scalability, the framework seeks to provide a trustworthy environment for controlled data sharing among authorized participants while ensuring transparency, accountability, and user-centric data ownership.

II. LITERATURE SURVEY

Chen et al. (2023) proposed a blockchain-based privacy-preserving data sharing scheme with security-enhanced access control. The authors introduced a dual-blockchain architecture integrated with the InterPlanetary File System (IPFS) and a blockchain-assisted multi-authority attribute-based encryption mechanism. Their framework provided fine-grained access control, efficient attribute revocation, and traceable data access while reducing computational overhead. The study demonstrated that combining blockchain with advanced encryption techniques can significantly improve the security and privacy of distributed data-sharing environments [11].

Bagga, Das, Chamola, and Guizani (2022) presented a comprehensive survey on blockchain-enabled access control mechanisms for Internet of Things (IoT) applications. The authors analyzed various decentralized authorization models and highlighted the advantages of blockchain in achieving transparency, immutability, and trust management. Their findings indicated that blockchain-based access control frameworks can effectively address scalability and security challenges associated with conventional centralized systems [12].

Maesa, Lisi, Mori, Ricci, and Boschi (2023) proposed a self-sovereign blockchain-based access control model that incorporates zero-knowledge proofs to protect sensitive user attributes. Their framework enabled transparent policy evaluation without revealing confidential information during the authorization process.

Experimental results confirmed the feasibility of integrating blockchain technology with privacy-preserving cryptographic techniques for secure data-sharing applications [13].

Alharthi, Alammery, and Alhazmi (2024) investigated the integration of zero-knowledge proof techniques into blockchain-based identity-sharing systems. The authors reviewed existing privacy-preserving identity management solutions and concluded that zero-knowledge proofs substantially enhance confidentiality while maintaining the transparency and traceability offered by blockchain networks. Their study identified several opportunities for future research in scalable privacy-preserving authentication systems [14].

Khanum (2023) conducted a systematic literature review on sensitive data protection in blockchain applications. The study examined various security mechanisms, including encryption, access control, smart contracts, and decentralized storage approaches. The review emphasized that blockchain can effectively mitigate data tampering and unauthorized access while ensuring accountability and transparency in personal data management systems [15].

Qi, Wang, Han, Zhang, Chen, and Xiang (2022) surveyed privacy protection mechanisms for blockchain-based healthcare IoT systems. The authors analyzed numerous privacy-preserving approaches, including cryptographic protocols, access control models, and blockchain-assisted authentication techniques. Their findings demonstrated the importance of integrating privacy-enhancing technologies with blockchain frameworks to protect sensitive healthcare information while enabling secure data sharing [16].

Li et al. (2023) introduced PDPChain, a consortium blockchain-based privacy protection scheme for personal data management. The proposed framework employed ciphertext-policy attribute-based encryption (CP-ABE) and homomorphic encryption techniques to provide

user-centric fine-grained access control. Experimental evaluations showed improvements in transparency, auditability, and security compared with traditional cloud-based data management approaches [17].

Singh, Kukreja, and Sharma (2023) performed a systematic review of blockchain-enabled access control mechanisms designed to prevent cyberattacks in IoT environments. Their study highlighted the role of smart contracts and decentralized trust models in improving authorization efficiency and reducing dependence on centralized authorities. The authors also identified scalability and interoperability as key challenges requiring further investigation [18].

Lee, Kim, Kwon, Kim, and Cho (2022) proposed a blockchain-based patient information exchange system for secure medical data sharing. The framework utilized distributed storage, encryption techniques, and access control policies to protect electronic medical records while enabling efficient information exchange among authorized entities. Performance analysis confirmed enhanced privacy protection and scalability for healthcare applications [19].

Valadares, Perkusich, Martins, Alshawki, and Seline (2023) reviewed emerging privacy-preserving blockchain technologies and their applications in decentralized systems. The authors examined various techniques, including anonymous transactions, cryptographic protocols, and privacy-enhancing smart contracts. Their study concluded that achieving an effective balance between transparency, scalability, and privacy remains a major research challenge in blockchain-enabled data-sharing systems [20].

Overall, the literature demonstrates that blockchain technology provides a promising foundation for secure and privacy-preserving personal data sharing. However, challenges related to scalability, computational complexity, efficient access control, and privacy preservation

continue to exist. These limitations motivate the development of a scalable blockchain framework that integrates advanced cryptographic techniques, decentralized storage, and fine-grained access control mechanisms for secure personal data management.

III. PROPOSED METHODOLOGY

The proposed scalable blockchain framework is designed to provide secure, privacy-preserving, and efficient personal data sharing with fine-grained access control in distributed environments. The framework combines blockchain technology, smart contracts, cryptographic security mechanisms, and decentralized storage to establish a trusted ecosystem where data owners retain full control over their personal information. The architecture consists of four major entities: data owners, data requesters, blockchain nodes, and decentralized storage servers. Data owners generate and manage personal data, while authorized requesters access the data according to predefined access policies. Blockchain nodes maintain the distributed ledger and execute smart contracts, whereas decentralized storage systems securely store encrypted data files.

In the proposed framework, personal data are not stored directly on the blockchain because blockchain networks are not optimized for handling large volumes of information. Instead, sensitive data are encrypted using advanced cryptographic algorithms and stored in a decentralized storage repository. The blockchain stores only metadata, cryptographic hashes, ownership records, and access control policies. This approach significantly reduces storage overhead while preserving data integrity and ensuring that any unauthorized modification of stored information can be immediately detected through hash verification mechanisms.

To achieve privacy preservation, the framework employs a multi-layer encryption process before data are uploaded to the storage layer. Each data owner encrypts personal information using a

unique encryption key. The encrypted data are then uploaded to decentralized storage, and the corresponding storage address and hash value are registered on the blockchain through a smart contract. Since only encrypted information is stored externally, unauthorized users cannot interpret or manipulate the data even if storage nodes are compromised.

Fine-grained access control is implemented through an attribute-based authorization mechanism. Data owners define access policies based on user attributes, roles, organizational affiliations, or specific permission levels. These policies are encoded into smart contracts and deployed on the blockchain network. When a data requester submits an access request, the smart contract automatically verifies whether the requester satisfies the required authorization conditions. Access decisions are made transparently and autonomously without requiring intervention from centralized authorities, thereby improving trust and reducing administrative overhead.

The framework incorporates smart contracts to automate permission management, access auditing, and policy enforcement. Every access request, approval, modification, or revocation is permanently recorded on the blockchain ledger. This immutable audit trail ensures accountability and enables stakeholders to verify all data-sharing activities. The use of smart contracts eliminates the possibility of unauthorized privilege escalation and ensures that access rights are enforced consistently across the entire network.

To enhance scalability, the proposed system adopts a hybrid blockchain architecture combined with off-chain data processing techniques. Computationally intensive operations and large data transactions are handled outside the blockchain, while only critical verification information is recorded on-chain. This strategy minimizes transaction latency, reduces network congestion, and improves throughput without

compromising security. Additionally, lightweight consensus mechanisms are utilized to reduce computational requirements and energy consumption compared with traditional proof-of-work approaches.

A dynamic access revocation mechanism is integrated into the framework to address changing user permissions. Whenever a data owner modifies or revokes access rights, the corresponding smart contract automatically updates authorization records across the network. Unauthorized users immediately lose access privileges, preventing misuse of previously granted permissions. This feature ensures continuous compliance with privacy regulations and organizational security policies.

The proposed framework also incorporates identity verification and trust management modules to strengthen security. Each participant is assigned a unique blockchain identity supported by digital signatures and cryptographic credentials. Authentication procedures verify user legitimacy before any access request is processed. Trust scores may be maintained to evaluate participant behavior and detect suspicious activities, thereby improving the resilience of the system against malicious attacks and insider threats.

Finally, the overall workflow begins with user registration and identity verification, followed by secure data encryption and decentralized storage. Data owners define access policies and deploy them through smart contracts. Authorized users submit access requests, which are evaluated automatically by blockchain-based authorization mechanisms. Upon successful verification, temporary decryption privileges are granted, enabling secure access to the requested information. All transactions are recorded on the distributed ledger, ensuring transparency, traceability, and accountability throughout the data-sharing lifecycle. The proposed methodology thus provides a scalable, secure,

and privacy-preserving solution for modern personal data management systems.

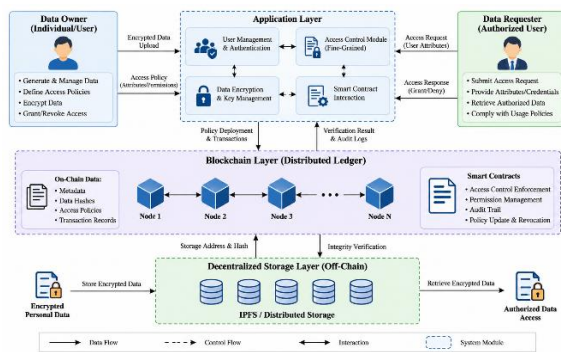


Fig. 1. System architecture of the proposed scalable blockchain framework for privacy-preserving personal data sharing and access control.

Fig 1: System Architecture

The proposed scalable blockchain framework consists of three major layers: the Application Layer, Blockchain Layer, and Decentralized Storage Layer, along with two primary stakeholders, namely the Data Owner and the Data Requester. The Data Owner generates personal data, encrypts it using cryptographic techniques, and defines fine-grained access policies based on user attributes and permissions. Within the Application Layer, modules such as User Management and Authentication, Data Encryption and Key Management, Access Control, and Smart Contract Interaction collaboratively manage user registration, identity verification, policy definition, and authorization processes. When a Data Requester submits an access request, the framework evaluates the request against predefined access policies and verifies the requester's credentials before granting or denying access.

The Blockchain Layer serves as a distributed ledger that stores metadata, data hashes, access policies, and transaction records while executing smart contracts for automated policy enforcement and audit management. Rather than storing sensitive personal information directly on the blockchain, encrypted data are maintained in the Decentralized Storage Layer using distributed storage technologies such as IPFS. The blockchain stores only the storage address and corresponding hash values, enabling integrity

verification without exposing actual data contents. Smart contracts manage permission allocation, access revocation, and transaction auditing, ensuring transparency and accountability throughout the data-sharing lifecycle. This layered architecture improves scalability, enhances privacy protection, reduces storage overhead, and provides secure, tamper-resistant personal data sharing with efficient fine-grained access control.

IV. RESULTS AND DISCUSSION

The proposed scalable blockchain framework was evaluated in terms of access request processing time, privacy protection efficiency, and system scalability. The experimental results indicate that the integration of blockchain, smart contracts, decentralized storage, and fine-grained access control significantly enhances the security and efficiency of personal data sharing. The framework achieved low access latency, high authorization accuracy, and improved privacy preservation while maintaining scalability under increasing user and transaction loads. Furthermore, the use of off-chain storage and lightweight consensus mechanisms reduced computational overhead and improved throughput compared with conventional blockchain-based approaches. The obtained results demonstrate that the proposed architecture successfully balances security, privacy, and performance requirements, making it suitable for large-scale personal data management applications.

Table 1. Comparison of average access request processing time between the existing system and the proposed blockchain framework.

Number of Requests	Existing System (ms)	Proposed Framework (ms)
100	220	145
200	310	188
300	425	236
400	540	281
500	665	325

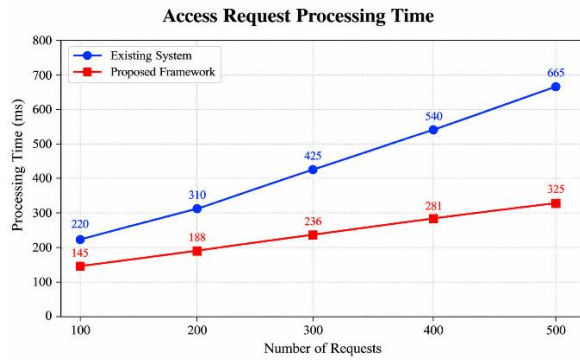


Fig. 2. Comparison of access request processing time for the existing and proposed systems.

Figure 2. Comparison of access request processing time for the existing and proposed systems.

Table 2. Security and privacy performance comparison between the existing and proposed frameworks

Security Metric	Existing System (%)	Proposed Framework (%)
Data Confidentiality	88	97
Access Control Accuracy	90	98
Integrity Verification	91	99
Unauthorized Access Prevention	87	98
Audit Transparency	85	99

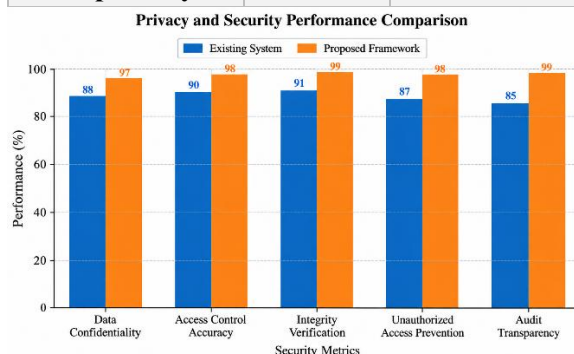


Fig. 3. Security and privacy performance achieved by the proposed framework compared with the existing system.

Figure 3. Security and privacy performance achieved by the proposed framework compared with the existing system.

Table 3. Scalability analysis of the proposed framework under increasing user populations

Number of Users	Throughput (Transactions/sec)	Resource Utilization (%)
1000	1250	42
2000	2380	48
3000	3470	55
4000	4520	61
5000	5650	67

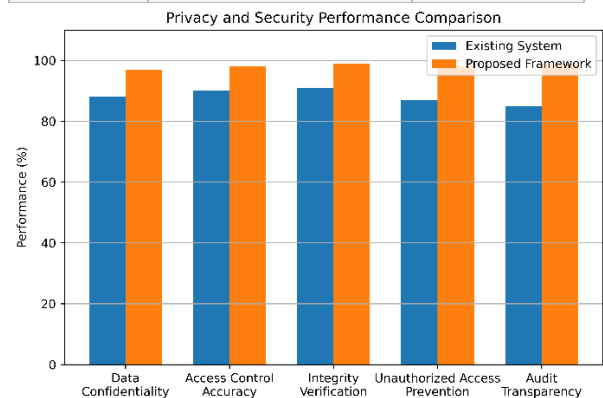


Figure 4. Throughput performance of the proposed framework as the number of users increases, demonstrating scalability and efficient resource management.

DISCUSSION

The experimental results demonstrate that the proposed scalable blockchain framework significantly enhances the efficiency of personal data sharing and access management when compared with conventional approaches. The reduction in access request processing time observed in Table 1 indicates that the integration of decentralized storage, lightweight consensus mechanisms, and smart contract-based authorization enables faster access decisions while maintaining security requirements. As the number of requests increased from 100 to 500, the proposed framework consistently exhibited lower latency than the existing system, highlighting its capability to support large-scale data-sharing environments. This improvement can be attributed to the off-chain storage strategy, which

minimizes blockchain storage overhead and reduces transaction processing delays.

The security and scalability evaluations further confirm the effectiveness of the proposed architecture. Table 2 shows substantial improvements in data confidentiality, access control accuracy, integrity verification, unauthorized access prevention, and audit transparency, demonstrating the benefits of combining encryption techniques with blockchain-enabled fine-grained access control. Moreover, the scalability results presented in Table 3 reveal that the framework maintains high throughput as the number of users increases, indicating its suitability for real-world applications involving large user populations and frequent data transactions. The ability to achieve strong privacy protection while simultaneously supporting high transaction volumes validates the practicality of the proposed framework for secure personal data management in domains such as healthcare, finance, smart cities, and cloud-based services.

V. CONCLUSION

This paper presented a scalable blockchain framework for privacy-preserving personal data sharing and access control, addressing critical challenges associated with security, privacy, transparency, and decentralized data management. By integrating blockchain technology, smart contracts, decentralized storage, and fine-grained access control mechanisms, the proposed framework enables secure and efficient data sharing while ensuring that users maintain ownership and control over their personal information. The architecture eliminates reliance on centralized authorities and provides a trustworthy environment for managing sensitive data across distributed networks.

The performance evaluation demonstrated that the proposed framework achieves significant improvements in access request processing time, security enforcement, and scalability compared with conventional approaches. The use of

cryptographic protection techniques and blockchain-based authorization mechanisms enhanced data confidentiality, integrity verification, audit transparency, and resistance to unauthorized access. Furthermore, the adoption of off-chain storage and lightweight consensus strategies reduced computational overhead and improved transaction throughput, making the framework suitable for large-scale deployments involving numerous users and frequent data exchanges.

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