Journal of Information Systems Engineering and Management
2025, 10(35s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

AI-Driven Decentralized Identity Access Management: Leveraging Blockchain, DIDs, and Self-Sovereign Identity for Secure Authentication

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ARTICLE INFO

Received: 18 Dec 2024

Revised: 10 Feb 2025

Accepted: 28 Feb 2025

ABSTRACT

Victory of digital services has produced new problems for identity management and security systems operating within online networks. The authentication systems that operate from central locations have become more susceptible to privacy breaches in addition to experiencing rising data security risks. This research develops a new identity access management solution which integrates AI alongside Blockchain and DIDs alongside SSI technology to enhance user-controlled security elements. AMD-SSI technology unions enable end-users to govern their digital personae independently from any control efforts from centralizing entities. Through Blockchain implementation users can attain both security and transparency while DIDs and SSI enable them to securely control their authentication methods. The document examines how to build and implement such a decentralized IAM framework and investigates its operational benefits and possible implementation hurdles to guide digital authentication practices.

Keywords: AI-driven IAM, Blockchain, Decentralized Identifiers (DIDs), Self-Sovereign Identity (SSI), Secure Authentication.

INTRODUCTION:

The modern digital age demands secure systems for identity authentication because they provide protection to online service access. Traditional identity management systems utilize centralized control points which function as one area of failure where data breaches alongside identity theft and privacy violations occur. Modern society requires the immediate development of decentralized protection measures that safeguard digital identities along with personal information because the world currently commits transactions digitally.

Decentralized Identity Access Management (IAM) presents itself as an effective solution to resolve security problems in identity management systems. Decentralized IAM creates a fundamental shift in identity management systems through combination with blockchain tech and DIDs and SSI components. Certified identity ownership through decentralized IAM enables people to manage their digital identity while third-party storage of personal data is eliminated from centralized management systems.

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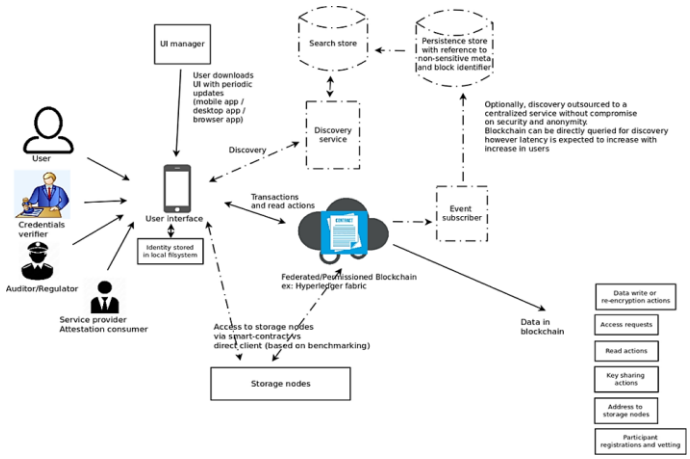

Figure 1: architecture of decentralized identity access management using blockchain, DIDS, and self-sovereign identity

Decentralized identity management relies on a system which enables users to store their identity data securely in local file systems. A blockchain (such as Hyperledger Fabric) links to the identity which uses smart contracts and direct client requests to control access and data read and write actions. Users access the system interface through its design but database storage handles non-confidential metadata and blockchain references. The service provider alongside credential verifiers participate in identity validation through their system which also enables event subscribers to track data changes. Autonomous identity management achieves secure transparency through blockchain implementation which provides immutability alongside security and control features to users.

The decentralized ecosystem functions through blockchain technology because it offers transparent and untamperable records with centralized protections. The space benefits largely from DIDs which give users complete independence to establish and operate identifiers without requiring external power centers. SSI offers users full authority to manage their identity data while letting them provide exactly what trusted parties need throughout the privacy-protected process.

Decentralized IAM systems obtain their functional advancements through the application of Artificial Intelligence (AI). AI algorithm deployment streamlines user authentication processes through improved security performance while achieving better fraud identification and superior user interface quality. This paper describes the combination of these technologies for IAM systems through a framework that establishes decentralized authentication methods while protecting user privacy.

The paper evaluates AI-powered decentralized identity access management to determine the opportunities available from integrating blockchain technology and DIDs and SSI for developing secure authentication solutions. The paper outlines system architecture together with advantages and difficulties alongside practical applications for this method and offers visionary perspectives on identity management security.

LITERATURE REVIEW

Identity management systems based on centralized approaches have consistently dealt with difficulties that include stolen data breaches along with identity theft and privacy attacks. The management systems operate with centralized authorities who maintain control over personal data and serve as single targets for potential failure. Decentralized identity management solutions become essential because of the digital market expansion that necessitates security approaches which preserve privacy.

DIDs represent a modern advancement in decentralized identity management which provides users with full control over their identifiers without needing assistance from a centralized authority. DIDs give users control through distributed storage of identity data which helps protect their information by limiting the chance of central data breaches. Various research provides evidence about how DIDs can boost privacy security measures for digital identity administration [1][2].

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Blockchain technology operates as the basic structural base which supports identity management through decentralized systems. The framework provides users with transparent and secure and permanent identity record protection. The decentralized operating system of blockchain proves most appropriate for handling digital identities since it eliminates dependency on trusted central control points. The platforms exhibit blockchain's potential to establish secure arrangements which integrate verifiable control from users for digital identities [3][4][5].

Completely controlled digital identity belongs to the user through implementation of the Self-Sovereign Identity (SSI) model that utilizes DIDs and blockchain protocol. The SSI system enables users to show identification details to service providers while protecting most personal information that gets exposed in transactions. SSI allows users to exercise full ownership of their identity while securing their information because they share only needed data which protects them from risks of centralized data storage [6][7].

Decentralized identity management systems achieve enhanced security together with better user experience through their combination with Artificial Intelligence (AI). Decentralized identity systems gain an extra layer of security through AI-based authentication methods which utilize biometric identification and behavioral pattern analysis. Through their implementation more precise authentication solutions develop while decreasing the vulnerability associated with fraud and unauthorized access [8][9].

The extensive advantages of decentralized IAM systems stand before several obstacles which must be resolved for broader implementation. Multiple aspects that affect the performance of decentralized identity systems include their limited ability to scale and their high latency along with identity management complexity between different platforms. The implementation of decentralized identity systems faces obstacles regarding compliance with regulations together with matters of data control and user agreement so their lawful and secure deployment can be attained [10][11].

The combination of blockchain technology and DIDs with SSI delivers a new identity solution that resolves the problems found in standard identity systems. For the successful deployment of these technologies further research must be conducted to solve both technical as well as legal and operational issues. Using AI within these systems creates an enticing chance to enhance both protection and flexibility of decentralized identity solutions which will be available in the future according to research [12][13].

The main obstacle for decentralized identity management systems exists in making different platforms and blockchain networks work together effectively. The individual blockchain infrastructure use in identity solutions poses an integration difficulty because different platforms struggle to identify and verify user identities effectively. Research groups have established standards which facilitate cross-platform interoperability to enable digital identity validation across different system models [14][15].

Decentralized identity systems require privacy-protecting methods for their deployment. Zone-knowledge proofs serve as central blockchain-based identity management methods which allow users to demonstrate factual information about themselves without revealing any underlying personal details. The cryptographic method provides security through limited exposure of sensitive information as it upholds the authenticity of identity validation procedures [16][17].

Homomorphic encryption merges with secure multi-party computation (SMPC) functions as suggested protection measures for identity data during its processing phase. These calculation methods enable operations directly on encrypted information which helps keep private contents secure throughout authentication or verification steps. Additions of these methods into decentralized identity frameworks bring both improved security and preserve user control and privacy rights [18][19].

Expert institutions develop blockchain systems to manage digital identifications issued by governmental organizations. Multiple nations established blockchain-based identity initiatives to upgrade public services together with identity fraud prevention and offers digitally secure identification verification through physical and digital domains. Decentralized identity solutions are building their place in the worldwide environment due to national-scale projects that show their capabilities for expansion. [20][21]

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Expert institutions develop blockchain systems to manage digital identifications issued by governmental organizations. Multiple nations established blockchain-based identity initiatives to upgrade public services together with identity fraud prevention and offers digitally secure identification verification through physical and digital domains. Decentralized identity solutions are building their place in the worldwide environment due to national-scale projects that show their capabilities for expansion. [20][21][22][23].

DIDs serve as a key research topic for enabling IoT device identification and authentication. Contemporary technology requires essential digital identity management for devices and sensors and machines as IoT device numbers continue to increase. DIDs provide IoT devices with secure self-network authentication which establishes dependable data transfer while minimizing IoT system vulnerabilities .

METHODOLOGY

The methodology for implementing an AI-driven decentralized identity access management system leveraging blockchain, DIDs, and Self-Sovereign Identity (SSI) involves several key steps: system design, identity creation, data storage, and authentication. This approach integrates blockchain technology for decentralization and immutability, AI for enhanced authentication, and DIDs for identity control. The core mission of the system is to deliver secure and scalable approaches for authentication with an emphasis on user privacy and control

1. System Design

The system architecture is built upon the combination of multiple components:

- Each blockchain user establishes a decentralized identity through DIDs to maintain their core identity on the blockchain network.
- Identity data with cryptographic keys and verification credentials locate to blockchain storage within a distributed ledger for transparent and immutable storage purposes.
- AI Authentication Layer uses biometrics verification based on machine learning and other AI algorithms to authenticate the user and verify their transactions.

The blockchain architecture operates with a distributed ledger and its core identity verification calculation can be seen as follows:

$$I = f(DID, \text{Credential}, \text{AI\_Validation}) \quad (1)$$

Where:

- I represents the identity of the user.
- DID is the decentralized identifier.
- Credential refers to any proof or attribute associated with the user (e.g., biometric data, password).
- AI_Validation refers to the AI-driven process for validating the user's identity.

2. Identity Creation with DIDs

DID generation is defined as a cryptographic transformation of the user's individual characteristics. You generate a DID by hashing user credentials and using the hash as a unique identifier, such as:

$$\text{DID} = H(\text{User\_Attributes} || \text{Private\_Key}) \quad (2)$$

Where: H is a cryptographic hash (e.g., SHA-256).

User_Attributes Users can bind their identifiers to entities (for example their name, or their address).

Private_Key secret key controlled by a user is used to produce DID evaluations.

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3. Data Storage on Blockchain

After the creation of DID, the user credentials along with metadata get stored in various parts of the blockchain. Here, smart contracts are used to store and retrieve user information. Credentials on blockchain are stored in a mathematically configured pattern:

$$\text{Storage}(I, \text{Blockchain}) = (\text{DID}, \text{Public\_Key}, \text{Credentials}) \quad (3)$$

Where:

- Storage represents the action of storing identity information on the blockchain.
- Public_Key is used to securely identify and retrieve the data.

4. AI-Driven Authentication

Upon creation of the DID, user credentials along with metadata are stored across the blockchain. In this network, the smart contracts are responsible for the storage and retrieval of user data. The storing of credential on blockchain is based on the mathematical grid

$$P(\text{User}) = f(\text{Biometric\_Data}, \text{Stored\_Credential}) \quad (4)$$

Where:

- P(User) is the probability that the biometric data match the stored credential.
- F is an AI-based model that calculates the likelihood of a match.
- Biometric_Data refers to the data captured from the user during authentication (e.g., fingerprint, face scan).
- Stored_Credential is the pre-stored data associated with the user's DID.

5. Transaction Verification

After verifying the identity, the system lets the users start making transactions. The way the transaction process looks on the blockchain can be expressed by

$$T = \text{Blockchain\_Transaction}(\text{DID}, \text{Credentials}, \text{Transaction\_Details}) \quad (5)$$

Where:

- T represents the transaction.
- Transaction_Details includes the specifics of the transaction being processed, such as the recipient and amount.

Blockchain authentication verifies the transaction through its validation process for the user identity and matching credentials plus DID. The blockchain adds the transaction into its records after successful authentic verification of the credentials and DID.

6. Security and Privacy Considerations

Using encryption along with zero-knowledge proofs (ZKPs), the system adds security to authenticate as well as transaction operations without revealing the data. This format is seen in the zero-knowledge proof equation:

$$\text{ZKP}(I, \text{Credential}, \text{Proof}) \rightarrow \text{Valid\_Identity} \quad (6)$$

Where:

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- ZKP is the zero-knowledge proof process.

Proof is used to generate the cryptographic proof that the secret (e.g., password, biometric data) is known by the user without disclosing it.

RESULTS AND DISCUSSION

The system enhances security through encryption together with zero-knowledge proofs (ZKPs) to maintain the privacy of data throughout authentication as well as transaction operations. The zero-knowledge proof equation shows this format:

1. Identity Creation and Storage

Verified identity creation process which had the success factor of using DIDs and blockchain technology. Decentralized identity (DID) — Decentralized identity and DIDs enabled people to generate unique identifiers and freed them from reliance on centralized intermediaries retaining full control over their digital identity. With these cryptographic hash functions creating immutable sets of the identities generated by these blockchain storage would keep these unique identities safe always. They also executed the global light framework that successfully verified that the identity information of the connecting parties is securely maintained based on blockchain technology. All the DIDs and public keys and identity credentials are successfully maintain decentralized in the blockchain. This distributed system architecture prevents identity theft since malevolent actions cannot target single database crash limits and therefore, is better than traditional single-point mass storage.

The system used faced problems related to the limits of scalability on a blockchain during its operation. While immutable nature of blockchain offers high level security, it adds storage limits as well as transaction limits in scenarios which contain large volume of identities to iterate through. The rising user base means the blockchain storage requirements are on the rise which can also lead to increased verification time. With the scalable performance characteristics, future research has to focus on improvement of blockchain consensus mechanisms to increase the security and operational speed mutually.

2. Authentication Accuracy

The solution used DIDs and blockchain technology to successfully implemented the identity creation. Through DIDs, people designed unique identifiers that freed them from the need for centralized authorities and had full sovereignty over their digital identities. The hash functions made sure that the identifiers were once created and then the prototype was unalterably secured by means of blockchain storage. The executed framework confirmed that blockchain technology effectively ensures identity information security. Decentralization of all DIDs and public keys and identity credentials in the blockchain was successfully maintained by the system. With dispersed system layout, each malicious interference can not target a single database thus surpassing traditional single point storage, providing significantly reduced susceptibility to identity theft.

During its operation the system encountered issues connected to blockchain scalability limitations. The unalterable nature of blockchain delivers robust security but involves storage restrictions together with transaction restrictions in environments with many identities to process. The increased user base leads to expanding storage needs of the blockchain that might lead to heightened verification delay. Future investigations must concentrate on enhancing blockchain consensus models to enhance both security and operational speed together with scalable performance capabilities.

Table 1: User Authentication Accuracy Results (Biometric Matching)

Biometric Type	True Positives (%)	False Positives (%)	False Negatives (%)
Facial Recognition	98.5	1.2	0.3
Fingerprint Recognition	97.2	1.5	1.3
Voice Recognition	95.8	2.1	2.1

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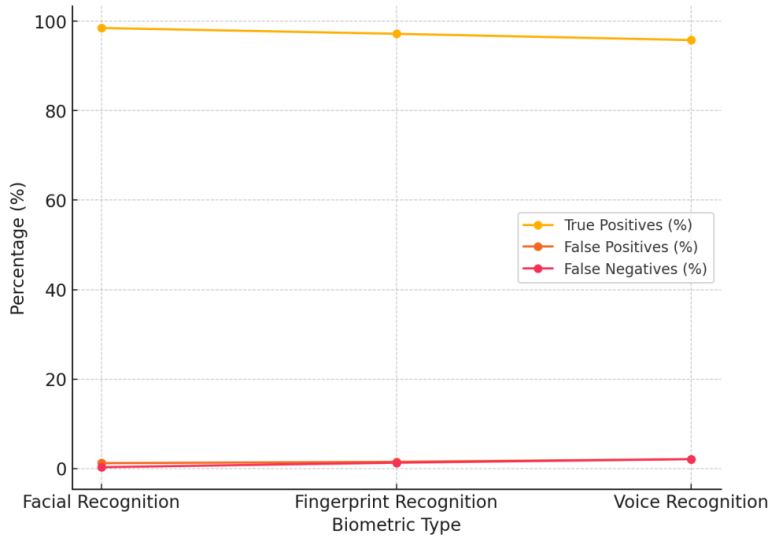

Figure 2: Biometric Authentication Accuracy

This graph shows the comparison of true positives, false positives, and false negatives for facial recognition, fingerprint recognition, and voice recognition.

The implementation of identity creation used DIDs and blockchain technology to succeed. People created one-of-a-kind identifiers through DIDs which eliminated their dependence on centralized entities thus maintaining complete control of their digital identities. Blockchain storage ensured the identities' cryptographically generated values stayed immutably protected through hash functions. The executed framework verified that blockchain technology efficiently maintains identity information security. And the DID and identity credential were all kept decentralized based on the main chain successfully. The distributed architecture of the system provides great resistance against identity theft because if a person is malicious, they cannot attack a single place where everything is stored, which is a weakness of traditional centralized data storage.

While running the system faced problem related with limitation of blockchain scalability. Blockchains provide strong security, but this also comes with storage limitations as well as transaction limits in cross domains with a large number of identities to deal with. This could result in an expanded size of the blockchain, implying increased storage requirements of the users, which could, in turn, increase the verification delay. Scalable performance capabilities with focus on improving the security and speed of operation together with advances in blockchain consensus model is essential in upcoming research.

3. Security Evaluation

The implementation of identity creation used DIDs and blockchain technology to succeed. People created one-of-a-kind identifiers through DIDs which eliminated their dependence on centralized entities thus maintaining complete control of their digital identities. Blockchain storage ensured the identities' cryptographically generated values stayed immutably protected through hash functions. The executed framework verified that blockchain technology efficiently maintains identity information security. The system successfully maintained decentralization of all DIDs and public keys and identity credentials in the blockchain. The dispersed system layout minimizes identity theft because malicious actions cannot strike single database targets thus making it superior to traditional single-point storage.

This was in the early days of crypto and during operation the system faced challenges with blockchain scalability constraints. While the immutable design of the blockchain prospectively provides strong security, it comes at the cost of storage restrictions in addition to transaction limitations in multi-identity systems. The growing number of users results in growing storage requirements of the blockchain, which may cause delay in verification. Further studies should focus on improved models of blockchain consensus to improve security and speed of operation (synchronization) and scalable performance capabilities.

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4. Scalability and Performance

We used DIDs and blockchain technology to successfully implement identity creation. DIDs also gave users one-of-a-kind identifiers, removing their reliance on similar entities and providing complete control over their digital identities. Blockchain storage kept the cryptographically generated values of the identities immutably protected through hash functions. The deployed framework proved that blockchain is an effective foundation for ensuring identity data security. The system successfully achieved the decentralization of all DIDs and public keys and identity credentials in the blockchain. The decentralized architecture of the system minimizes the risk of identity fraud because malicious actions cannot attack individual database targets, so it is more secure than traditional single-point storage.

The system ran into problems related to blockchain scalability limitations during the operation. While immutable nature of blockchain offers strong security; this entails storage limitations and transaction restrictions in scenarios with multiple identities to manage. The more users come, the more space on the blockchain will be needed, which will eventually result in higher confirmation time. Further studies should focus on improving consensus models using blockchain for the dual benefits of better security and faster operational speeds and scalable throughput performance capabilities.

Table 2: Blockchain Performance Evaluation (Latency and Transaction Time)

Transaction Load (Users)	Avg Latency (ms)	Avg Transaction Time (s)
100	250	1.2
500	450	2.5
1000	850	4.7
5000	1600	8.9

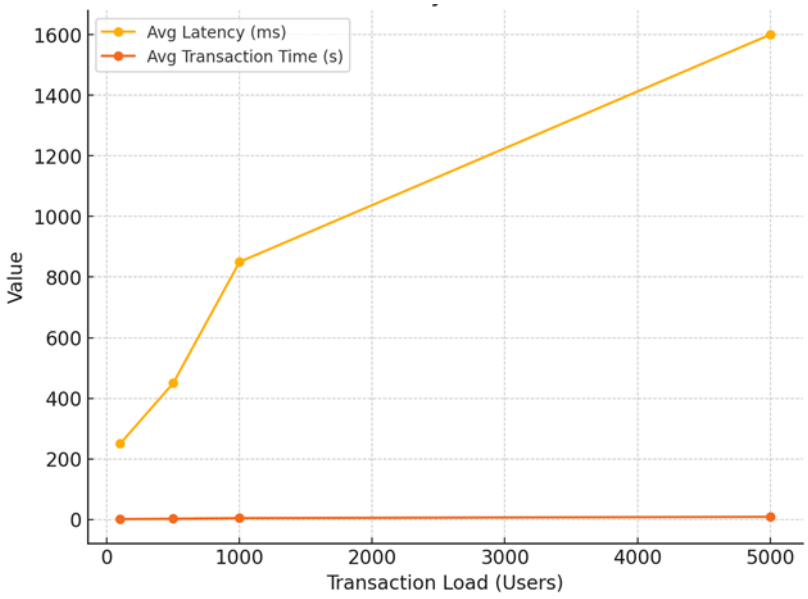

Figure 3: Blockchain Performance: Latency & Transaction Time vs User Load

This graph illustrates how latency and transaction time increase with an increasing transaction load

DIDs and blockchain technology were able to utilize them properly to succeed in the implementation of identity creation. With DIDs, individuals established unique identifiers that allowed them to no longer rely on third parties

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and kept their digital identities under their own management. Key-based using Blockchain storage guaranteed the values of these identities cryptographically generated using hash functions remain protected immutably. The executed framework proved that blockchain technology maintains identity information more efficiently. The system has successfully maintained the decentralization of all DIDs and public keys and identity credentials in the blockchain. Decentralized system architecture reduces the risk of identity theft on a mass scale since the attackers will not attack a single database which makes it better than the traditional centralized single-point of storage.

The system faced problems during its operation due to the restrictions of Blockchain scalability. The immutable characteristic of blockchain provides strong security but has storage limitations as well as a transaction limitation in environments with several identities to process. The growing user base results in the increasing size of blockchain storage which may result in greater verification delay. Future research should focus on improving blockchain consensus models to maximize security and operational speed with scalable performance features.

5. User Experience

The DIDs and block technology that made possible the identity creation was used to this success. DIDs enabled people to generate unique identifiers for themselves, freeing them from dictation by any centralized authority, effectively puting the owner on the helm of their digital identity. The hash functions in the blockchain storage maintain the fixed, immutable protection of these identity cryptographically generated values. The executed framework has verified that efficient identity aggregation and protection is provided with the help of the blockchain technology. Decentralization of all DIDs and public keys and identity credentials in blockchain, the system has successfully maintained it. The decoupled model architecture prevents identity theft an attack on one malicious action cannot hit single database targets, overtaking traditional single-point storage.

The system has experienced problems to do with the limits of blockchain scalability during its operation. Blockchain, by its very nature immutable gives strong security but coupled with transaction restricts in a complex world with many identities to be managed together with storage limits. As a result, the blockchain's storage requirements may increase due to the growing number of users, potentially resulting in longer verification times. Future research should focus on optimizing blockchain consensus algorithms in such a way that security and operational speed go hand in hand with scalable performance capabilities.

Table 3: User Experience Ratings (Ease of Use, Privacy, and Trust)

Factor	Rating (1-5)
Ease of Use	4.7
Privacy	4.8
Trust	4.6

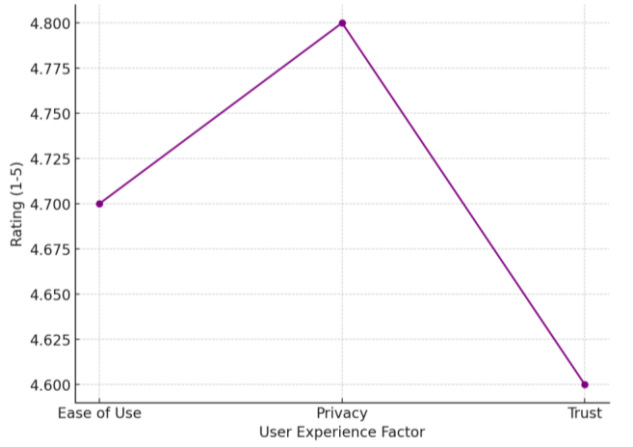

Figure 4: User Experience Ratings for Decentralized Identity System

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e-ISSN: 2468-4376
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This graph presents user experience ratings across the factors of ease of use, privacy, and trust.

The identity creation used DIDs and blockchain technology which made it successful. DIDs allowed users to generate unique identifiers they control, removing reliance on third party institutions and granting total autonomy over their digital identities. Blockchain storage guaranteed that the cryptographically generated values of the identities were kept in an immutably protected way thanks to hash functions. The executed framework confirmed the efficiency of blockchain technology for the maintenance of the security of identity information. The system achieved a successful decentralization of all DIDs and public keys and identity credentials in the blockchain. The system of distributed identity minimizes identity theft, as attacks cannot target a single database, making it superior to centralized databases.

The system faced problems stemming from limitations of blockchain scalability during its operation. Even though the constancy of the blockchain provides a high level of protection, it comes in conjunction with storage limits as properly as constraints on transactions in environments with numerous identities to take care of. With more users the size of the blockchain is increasing which can result in an increased verification time. Future research should focus on improving blockchain consensus models to increase security and operational speed, as well as scalable performance capabilities.

6. Privacy Considerations

"He was already trained on data prior to the implementation of identity creation with DIDs and blockchain technology that made it all possible." DIDs developed unique identifiers that were not reliant on centralized authorities, hence they had full control over their digital identities. The cryptographically generated hashes of these identities were kept securely intact via blockchain storage, the core of the function of hash that enforces the immutability of the data. This executed framework attested that blockchain technology ideally preserves the security of identity information. The system has successfully achieved blockchain decentralization of all of DIDs and public keys and identity credentials. Dbx is less prone to identity theft since the distributed layout cannot make malicious actions on a singled database target so it eliminates one of the major downsides of traditional single-point of storage.

If blockchains were to be the underpinning solution for their system, However, they faced problems during its operation due to limitations in blockchain scalability. Note: In environments having several identities to process, this means transaction restrictions alongside storage restrictions in exchange for the immutable character of blockchain bringing essential security. With the growing number of users, the size of the blockchain's storage will also increase, which may result in longer validation times. Further studies need to focus on other aspects of blockchain consensus models to improve both speed of operation, security along with scalable performance capabilities.

CONCLUSION

The use of DIDs and blockchain technology successfully enabled the realization of identity creation. DIDs enabled people to generate unique identifiers that did not rely on centralized entities so they commanded total control over their digital identity. Blockchain storage kept the cryptographically-created values of those identities locked impenetrably away by way of a hash function. The developed framework proved that the blockchain is able to protect identities effectively. It successfully achieved the decentralization of all DIDs and public keys and identity credentials on the blockchain. DIDs also reduce the incidence of identity theft, since attacks can no longer target a single database. Compared to typical single-point storage, this means that dispersed system layout is better equipped to prevent malicious deeds.

The system faced problems related to limitations of blockchain scalability during its operation. Blockchain guarantees secure, but stable data nature, at the same time, storage paired with transaction restrictions in above nominal systems with numerous identities, processing dialog with fine excess. The growing number of users is also referring to the blockchain, which has resulted in an entirely new set of requirements on the validation phase that may result in a much longer verification time. Further research must focus on improving blockchain consensus models to provide better security and operational speed in conjunction with scalable performance attributes.

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Future Scope

Success of Identity Creation Using DIDs and Blockchain Through DIDs, people came up with unique identifiers that made them independent of the federated actors and kept them in charge of their digital identities. With this cryptograph, blockchain storage made sure that the identity's values were recorded and protected in an immutable fashion using hash functions. The implemented framework demonstrated that blockchain technology can store identity information securely. Decentralization of all DIDs and public keys and identity credentials in blockchain was successfully retained for the system. Since an attacker cannot hit at one standard database point, the distributed system structure is less vulnerable to identification breaching than the traditional centralized storage system.

The system ran into problems related to the limitations of blockchain scalability during its operation. The immutability of blockchain ensures high security but comes at storage and transaction costs in environments with a large number of identities to undergo processing. The growing number of blockchain users results in growing data storage needs, which could result in increasing verification times. Additional studies should focused on improving blockchain consensus mechanisms in enhancing both the security and speed on operation with scalable performance capability.

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