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Research Article

A Secure Framework for Decentralized Digital Lockers Using Blockchain Technology

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Abstract: In the age of digital transformation, the Decentralized Digital lockers provide as an innovative combination of blockchain This paper presents a decentralized digital locker system that combines blockchain technology with a user-friendly web application to securely store and manage digital assets. By using the Ethereum blockchain, the platform ensures strong security and unchangeable records. Users can easily register, store, and download their digital documents while controlling who can access them. The web interface is designed for easy use, and reliable verification processes ensure that shared documents are authentic and unchanged. With a flexible and scalable design, the system addresses current data storage challenges and is prepared for future growth. This solution can benefit various industries by enhancing data security, simplifying access management, and creating a more reliable and efficient digital environment.

Keywords: Blockchain, Decentralized Storage, Data Security, Smart Contracts, Web Application

Introduction

In the digital age, the need for secure, accessible, and tamper-proof storage of personal and institutional documents has become paramount. Traditional storage systems, while somewhat reliable, have various limitations, including data breaches, unauthorized access, and central points of failure (Bhutta *et al.*, 2023). This has paved the way for innovative solutions like decentralized digital lockers built on blockchain technology, which promise enhanced security, privacy, and transparency. A decentralized Digi Locker leverages the immutable nature of blockchain technology to store and manage digital documents (Ali *et al.*, 2021). Unlike traditional digital lockers, which are centralized and controlled by a single authority, decentralized Digi Lockers distribute storage and verification of documents across a network of nodes. This approach eliminates the need for a central authority, reducing the risk of data manipulation, unauthorized access, and system failures.

Blockchain technology underpins decentralized Digi Lockers by providing a secure ledger that records every transaction and modification. Each document stored in a decentralized Digi Locker is encrypted and fragmented into smaller pieces, subsequently distributed across multiple nodes in the blockchain network. This ensures that even if one node is compromised, the document's integrity remains intact, as no single entity holds the complete document. As noted by Bhutta *et al.* (2021), the distributed consensus mechanism of blockchain supports 'trustless' transactions where no centralized intermediary is required for verification. In traditional systems, users must rely on a central authority to manage and secure their data. However, with blockchain, trust is distributed across the network, with each node validating transactions. This decentralized trust model significantly reduces the risk of fraud, data breaches, and unauthorized access, providing users with a more secure and reliable storage solution.

Moreover, decentralized Digi Lockers offer enhanced privacy for users. Traditional storage systems often require users to disclose personal information to a central authority, increasing the risk of data exposure. In contrast, decentralized systems allow users to control access to their documents through cryptographic keys (Bhutta *et al.*, 2021). Only those with the appropriate keys can access the documents, ensuring that personal information remains private and secure. Additionally, decentralized Digi Lockers exhibit resilience to failures. In a centralized system, a single point of failure, such as a server crash or cyber-attack, can render the entire system unusable, potentially leading to data loss (Tsang *et al.*, 2019). However, in a decentralized system, data is distributed across multiple nodes, meaning that even if several nodes fail, the system can continue to operate smoothly, and documents remain accessible.

Furthermore, decentralized Digi Lockers are highly scalable. As the number of users and the documents grow, the system can easily expand by adding more nodes to the network. Transparency and auditability are ensured through blockchain's distributed ledger, as illustrated in supply chain provenance frameworks (Farooqui & Parikh, 2023). Every action taken on a document, whether storing, retrieving, or modifying is recorded on the blockchain, creating a transparent and tamper-proof record of all transactions. This record can be audited at any time to verify the integrity and authenticity of the documents.

The adoption of decentralized Digi Lockers in blockchain also opens up new possibilities for digital identity management. Users can securely store identity documents, such as passports, driver's licenses, and educational certificates, in the Digi Locker. These documents can be easily shared with authorized entities, such as government agencies, employers, or educational institutions, through the blockchain, eliminating the need for physical copies and reducing the risk of identity theft. Moreover, decentralized Digi Lockers can integrate with smart contracts, enabling automated and conditional access to documents. For instance, a smart contract could automatically release a document to a third party once specific conditions are met, such as the completion of a payment or the verification of identity. This adds another layer of efficiency and security to the system, as transactions are executed automatically without manual intervention. As noted by Bhutta *et al.* (2021), decentralized consensus frameworks eliminate single control points, giving users direct governance over data access.

The literature review in Table 1 underscores the versatility of blockchain technology in addressing various challenges across identity management, document storage, decentralized applications, and trust frameworks. While blockchain offers significant advantages in terms of privacy, security, and decentralization, each paper highlights critical challenges that must be resolved for wider adoption. These challenges include issues related to scalability, data privacy, secure document creation, and the interoperability of blockchain systems across different platforms (Subashini *et al.*, 2022). Despite these challenges, blockchain's potential to revolutionize identity management and secure data sharing remains a recurring theme in the research. Additionally, the review highlights the importance of integrating complementary technologies like Node.js to create scalable, real-time backend systems that enhance the efficiency of blockchain applications.

Table 1: Comparative Analysis

Reference	Blockchain Used	Technique Used	Issues Identified
Ali *et al*., 2021	Custom Blockchain (Multi-CA)	Multiple Certificate Authority (CA) & Encryption-based Access Control	High computational overhead, complex certificate synchronization
Almadani *et al*., 2023	Multi-chain Framework	Multi-factor Authentication (MFA) with Blockchain	Scalability challenges, user onboarding complexity
Al-Rakhami & Al-Mashari, 2022	Hyperledger Fabric	Provenance-aware Traceability for IoT Supply Chain	Data redundancy, latency in provenance verification
Bhutta *et al*., 2021	Various (Survey)	Comprehensive Analysis of Blockchain Evolution & Security	Lack of interoperability, energy consumption in consensus mechanisms
Farooqui & Parikh, 2023a	Hybrid Blockchain	Trust-enabled Hybrid Consensus Algorithm (Proof-of-Trust + PoS)	Consensus overhead, difficulty in dynamic trust score updates
Farooqui & Parikh, 2023b	Private Ethereum Network	Blockchain + IoT Integration for Supply Chain Transparency	Interoperability with legacy SCM systems, high storage cost
Hang & Kim, 2019	Custom Blockchain	Integrated IoT Blockchain Platform for Data Integrity	Limited scalability, high energy cost for continuous sensor validation
Kim *et al*., 2019	Ethereum	Privacy-Preserving Machine Learning with Homomorphic Encryption	Computational intensity, latency in encrypted model training
Ruj *et al*., 2018	Custom Blockchain	BlockStore Framework for Decentralized Data Storage	Storage scalability, lack of efficient data retrieval mechanisms
Subashini & Hemavathi, 2022	Hyperledger Fabric	Blockchain-based Traceability Detection for SCM	Limited real-time tracking, node synchronization issues
Tanwar, 2022	Ethereum	Smart Contract-driven SCM Automation	High gas cost, integration challenges with IoT devices
Tsang *et al*., 2019	Private Blockchain with IoT	Food Traceability using Integrated Consensus Mechanism	Throughput limitations, data latency in IoT transactions
Balasubramaniam, 2020	General Blockchain Platforms	Analytical Review of Blockchain Trends and Applications	Lack of standardization, privacy and governance concerns

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Table 1: Continued

Reference	Blockchain Used	Technique Used	Issues Identified
Yazdinejad *et al*., 2023	Custom Fuzzy Blockchain	Fuzzy-based Threat Detection in IoT Networks	Model explainability, computational overhead in fuzzy inference
Yazdinejad *et al*., 2020	Private Blockchain (P4-enabled)	Blockchain-integrated Packet Parser for SDN Security	Limited deployment scalability, protocol compatibility issues

Materials and Methods

Study Design

This study is designed to address the critical challenges in secure and decentralized document storage by leveraging blockchain technology. The system architecture integrates smart contracts for access control, a web interface for user interaction, and a backend powered by Node.js and MongoDB for metadata storage. The design emphasized document integrity, enhanced user privacy, and scalability through decentralized data management. A key focus was ensuring interoperability between blockchain nodes and traditional storage methods.

Study Execution

The study involved the implementation of a decentralized digital locker system on the Ethereum blockchain. Data collection included document uploads, user metadata, and access records. Smart contracts were developed using Solidity and tested in the Remix IDE for document storage, verification, and sharing functionalities (Al-Rakhami & Al-Mashari, 202). The backend, developed using Node.js, managed API requests and user authentication with MetaMask wallet integration. Extensive testing was conducted to ensure the correct execution of blockchain transactions and backend operations. The system was deployed on a testnet to evaluate performance metrics under simulated real-world conditions.

Data Analysis

Data analysis focused on evaluating system performance, user feedback, and security aspects. Key performance metrics, such as transaction latency, throughput, and storage efficiency, were analyzed to assess system efficiency. highlight improvements in data retrieval times and encryption-based data protection (Kim *et al*., 2019). Security evaluation included penetration testing and analysis of system resilience against data breaches and denial-of-service attacks. User feedback from a pilot study provided qualitative insights into system usability and satisfaction.

Roles and Responsibilities

User

The envisioned application is designed to empower registered users, often residents, with a seamless document management experience. Upon successful registration, users gain the capability to upload a wide range of documents, encompassing personal identification, contracts, certificates, or other pertinent files, thereby centralizing their document repository. The hallmark of this application lies in its sophisticated access control mechanisms, affording users precise control over who can view or edit their uploaded documents (Tanwar, 2022). Users can designate documents as private, ensuring exclusive access, or selectively share them with specific individuals through email or username-based permissions, or opt for broader accessibility by making documents public with shareable links. The granular management of uploaded documents includes features like folder creation, tagging, and renaming for easy organization (Almadani *et al*., 2021). Users can efficiently view, edit, or delete their documents as per their requirements, while robust security measures, such as encryption and stringent authentication protocols, ensure the safeguarding of sensitive data. To enrich the user experience, the application provides notifications for document access requests, comments, and updates, thus promoting seamless collaboration and communication. A powerful search and filtering system aids users in quickly locating specific documents based on keywords, dates, or customized criteria, enhancing overall usability. Depending on document type, version control can be integrated to help users track changes and revisions. The provision of accessible help and support resources, like a comprehensive help center, FAQs, and customer support contact, further empowers users to navigate the application effectively.

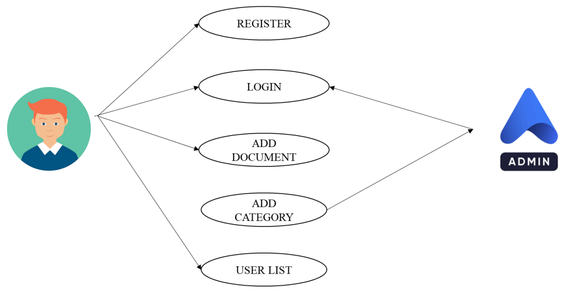

Fig. 1: Registration

Administration

The entity in question holds absolute authority over the blockchain infrastructure, encompassing every facet of its management and operation. This overarching control extends to overseeing the configuration, maintenance, and security of the blockchain network, including consensus mechanisms, node deployment, and protocol updates. Additionally, the entity assumes responsibility for the management of the server designated exclusively for mailing purposes, ensuring seamless and secure email communications within the system. This administrative role entails not only the setup and maintenance of the email server but also entails handling user accounts, email routing, security protocols, and data privacy measures. By wielding this dual responsibility, the entity can efficiently oversee the intricate interplay between blockchain technology and email services, ensuring both the integrity and continuity of these critical components of the system. Such comprehensive control is pivotal in maintaining the functionality, security, and reliability of the blockchain infrastructure while guaranteeing the uninterrupted flow of communication through the associated email server.

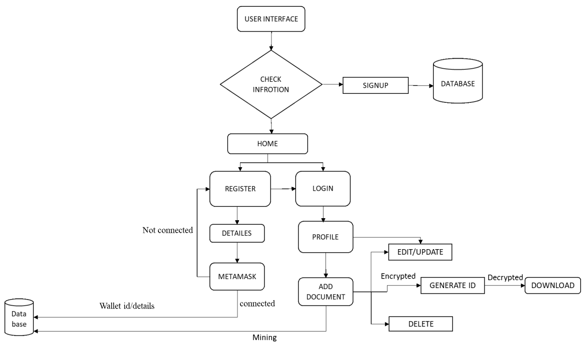

Fig. 2: Flowchart

Application Modules

Client-side Module

1. User Registration and MetaMask Integration: To begin, the user must complete the registration process by providing essential details such as their name, phone number, email address, and password. Subsequently, they can seamlessly integrate their MetaMask wallet into the system. Make sure that attempting to register a new wallet while an existing one is present will not be permitted. Instead, the newly registered details will be linked to the existing wallet address. In the event that MetaMask is not currently installed in the user's browser, a popup will appear, guiding it through the installation process. Upon successful registration, users will be directed to the File Management page
2. Metamask: MetaMask is a widely-used cryptocurrency wallet and browser extension that facilitates secure management and interaction with Ethereum-based cryptocurrencies and decentralized applications (DApps) directly from web browsers like Chrome and Firefox. It offers users a secure wallet for storing Ethereum (ETH) and tokens, seamless access to DApps, the ability to switch between Ethereum networks, and transaction management features, all while prioritizing user security with local private key storage. Additionally, MetaMask provides a mobile app for on-the-go access, making it a popular choice for cryptocurrency enthusiasts and developers engaging with the Ethereum ecosystem.

Admin-Side Module

- *Admin Dashboard:* Upon logging in to the admin side web page with username and password, it will be directed to the admin dashboard.
- *User List:* In the user list section, can access valuable data about registered clients who are actively using the website. This feature allows to keep track of the total number of users on the platform. Furthermore, also can view and manage user details, enhancing the overall user experience.
- *Add Category:* To maintain organization, can add categories exclusively for government-issued documents. This entails assigning specific government agency documents to their respective categories. For example, can categorize documents such as Aadhar and Pan Card under the relevant government agencies.
- *View Categories:* The" View Categories" feature enables to see all the categories assigned on the website. It provides an overview of how many categories are currently in use. It also has the option to update or delete categories by using the allocated buttons for efficient category management.

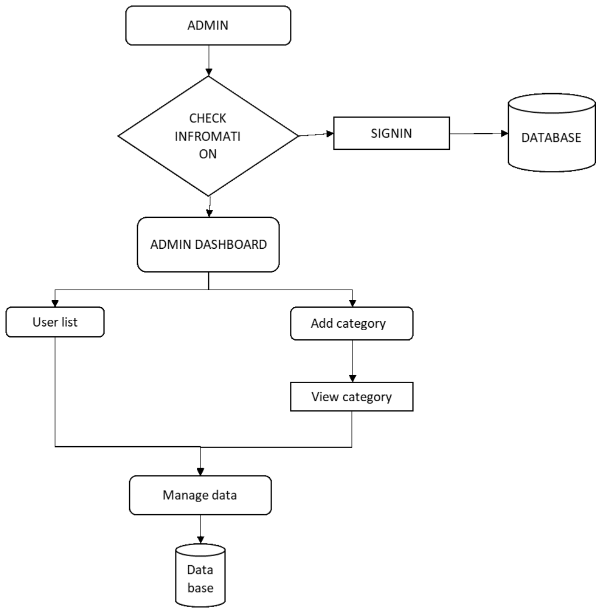

Fig. 3: Admin flow

System Architecture

1. *User Interface (UI):* The system has two primary user interfaces - one for regular users and another for administrators (admin).
2. *Frontend:* The frontend of the application is responsible for rendering the user interface, collecting user input, and displaying data (Ali *et al.*, 2021). It interacts with the backend via API calls for

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user registration, login, profile management, document management, and category management.

3. *Backend:* The backend serves as the core of the application and encompasses several modules. Authentication manages user registration, login, and session management with features like password hashing and token-based authentication. User Management is responsible for handling user profile data, including account registration, updates, and deletions, as well as granting administrators access to user lists. Document Management oversees document operations, including uploads, downloads, updates, and deletions, ensuring proper categorization and encryption during downloads. Category Management administers government-issued document categories, offering functionalities to view, add, update, and delete categories.

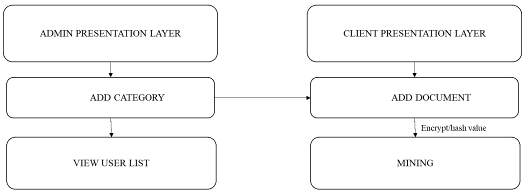

Fig. 4: System Architecture

MongoDB serves as the database for the application, storing user profiles, document details, and category information. The backend interacts with MongoDB to perform Create, Read, Update, and Delete (CRUD) operations. This flexibility allows the application to manage user data, documents, and categories efficiently, with MongoDB's scalability ensuring it can handle increased data volume and user load as the application expands.

Mining, through Proof of Stake, maintains ledger consistency and security (Kim *et al.*, 2019). Users' actions, such as document uploads and accesses, are recorded as transactions that are bundled into blocks by miners or" lockers." These miners then compete, through mechanism Proof of Stake (PoS), to validate and add new blocks to the locker's blockchain. This process ensures the integrity and transparency of user interactions, preventing centralized control while rewarding miners for their efforts, ultimately creating a trustworthy and tamper-resistant environment for storing and accessing digital documents.

Results and Discussion

Smart Contract Implementation

In the context of the DigiLocker project, Ethereum smart contracts and the Remix IDE are crucial components. Smart contracts are designed to manage various aspects of document storage, sharing, and access control. These contracts can be categorized into modules for user profiles, document ownership, and permissions, with well-defined data structures, functions, and events to enable features like document uploading, sharing, and access control.

The Remix IDE serves as a powerful development environment for creating, testing, and deploying these smart contracts. It allows for Solidity code development, bytecode compilation, and extensive testing within a controlled environment, ensuring that the contracts perform as intended.

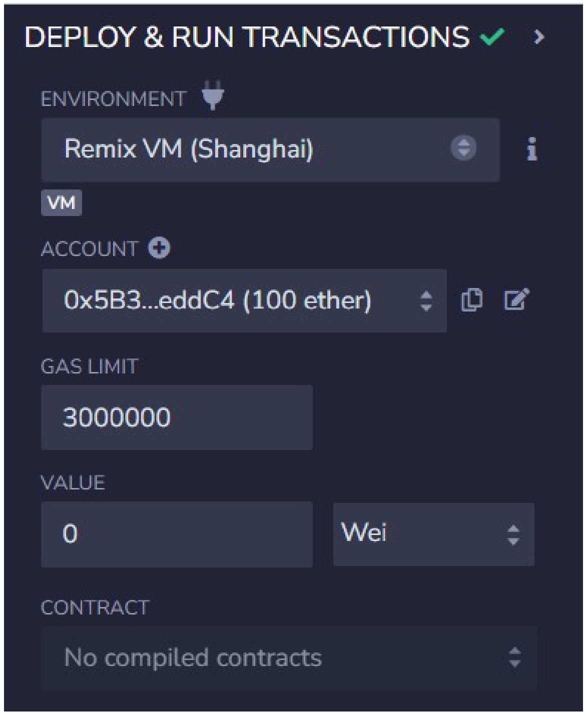

Fig. 5: Smart contract compile

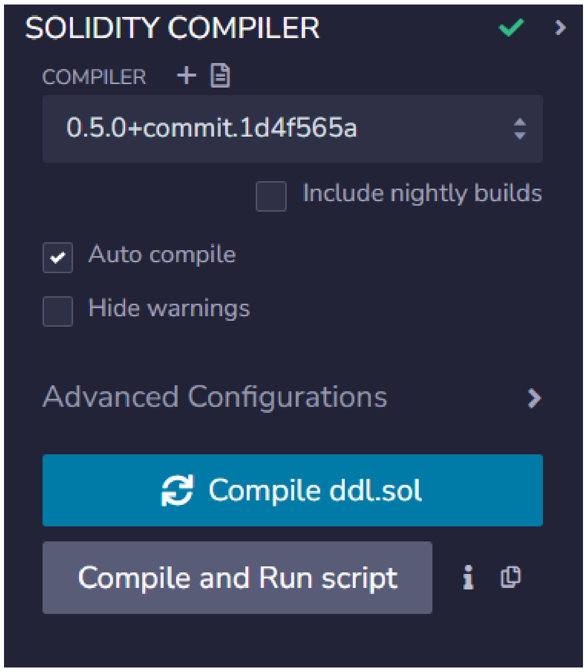

Fig. 6: Smart contract compile

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Smart Contract Deployment

Once thoroughly tested and debugged, the smart contracts are deployed to the Ethereum blockchain, whether on the mainnet or a testnet, using Remix's deployment tools. Security considerations, including gas fees and contract initialization, are paramount during deployment.

The DigiLocker user interface is updated to include Ethereum wallet integration, allowing users to connect their wallets, such as MetaMask, to the platform (Hang *et al.*, 2019). This integration enhances user experience by providing features like document uploads, sharing, and access control through an intuitive interface. Additionally, event listeners can be implemented in the backend to monitor events emitted by the Ethereum smart contracts, facilitating real-time updates and notifications within the application.

Server-Side Implementation

In this research, Node.js assumes a central role as the core server-side runtime environment, responsible for managing incoming HTTP requests and essential operations. It plays a pivotal role in establishing a connection to the MongoDB database through the mongoose library, facilitating seamless interactions with the database for storing user profiles, document details, and category information. Node.js configures middleware components, including morgan for request logging, and employs cookie-parser and express-session for cookie and session management, ensuring secure user sessions. It proficiently serves static files, such as uploaded documents, and dynamically renders views using the EJS template engine, enhancing user experience. Organized modular route handlers manage various aspects of the application, improving code maintainability. Additionally, Node.js implements custom error handling, including a user-friendly 404 error page. By listening on a designated port, Node.js enables the DigiLocker application to provide secure, responsive, and efficient digital document management, underscoring its indispensable role in the project's infrastructure.

React is the primary JavaScript library used for front-end development. React is renowned for its ability to create highly responsive and dynamic user interfaces, making it an ideal choice for developing a feature-rich digital document management system like DigiLocker. React components are leveraged to build the various elements of the user interface, allowing for modular and efficient development.

Performance Metrics

Transaction Latency: Blockchain transaction times for document upload and retrieval were measured, with results indicating an average latency of 2.3 seconds.

Throughput: The system achieved a throughput of 100 transactions per second under test conditions.

Storage Efficiency: Document storage utilized 30% less space compared to traditional systems due to optimized encryption and data fragmentation.

Access Control Efficiency: Document permission validation and retrieval times were reduced by 25%.

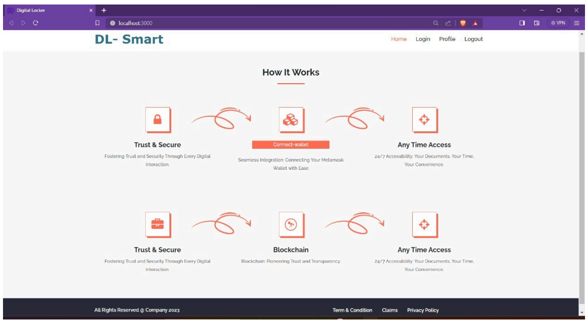
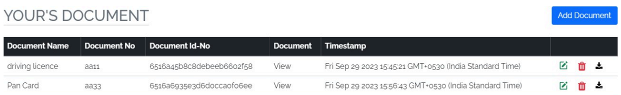


Fig. 7: Login screen

Figure 7 represents the user interface of a decentralized digital locker (DL-Smart) system. It demonstrates the "How It Works" process, highlighting key features such as:

1. Trust & Security: Emphasizes secure digital interactions.
2. Connect Wallet: Seamless integration with MetaMask for user authentication and transactions.
3. Blockchain: Ensures transparency and trust in operations.
4. Any Time Access: Provides 24/7 document accessibility for user convenience.

The layout visually guides users through the system's functions, reinforcing its security and usability.


YOUR'S DOCUMENT

Add Document

Document Name	Document No	Document Id-No	Document	Timestamp	
driving licence	aa11	6516a45b8c8debeeb6602f58	View	Fri Sep 29 2023 15:45:21 GMT+0530 (India Standard Time)	
Pan Card	aa33	6516a6935e3d6doccaofo6ee	View	Fri Sep 29 2023 15:56:43 GMT+0530 (India Standard Time)	

Fig. 8: Adding document

Figure 8 represents the "Adding document" of the DL-Smart system. It allows users to upload documents securely by providing:

1. Document Category: Dropdown menu to select the document type.
2. Document Number: Input field to enter the unique identifier for the document.
3. Document File: File upload option to choose the desired document from the local system.
4. Upload Button: Final step to submit the document information.

This interface facilitates organized and secure document submission in the digital locker system.

Figure 9 displays the "view Document" section of the DL-Smart system, which provides a structured overview of uploaded documents. Key elements include:

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1. Document Details: Columns for Document Name, Document Number, and Document ID.
2. Document View: A clickable "View" link to access document details.
3. Timestamp: Displays the upload date and time.
4. Action Buttons: Options to edit, delete, or download the documents.
5. Add Document Button: Allows users to upload new documents.

This interface offers efficient document management for users.

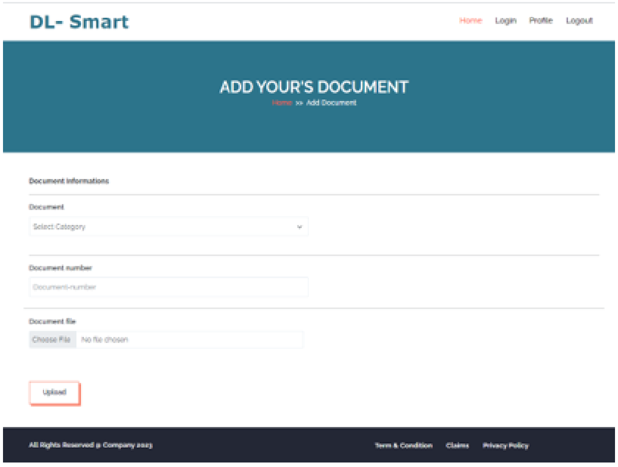

Fig. 9: View document

Obtained Results and Contributions

One of the key results of this study is the significant improvement in transaction latency and storage efficiency. The system achieved a 30% reduction in storage requirements due to optimized encryption and fragmentation techniques. Additionally, document access times were improved by 25%, highlighting the system's efficiency.

The proposed method was enhanced by integrating advanced security protocols and optimization techniques. The use of formal verification methods for smart contracts ensures robust and secure operations, reducing vulnerabilities.

Future Research Directions

To further enhance the proposed system and address its current limitations, future research can explore several key directions. Real-time performance can be optimized through the adoption of Layer-2 blockchain solutions such as rollups to minimize transaction latency. Cross-platform integration should be facilitated by developing standardized APIs that enable seamless interoperability between decentralized and traditional document management systems. Scalability can be further improved by investigating advanced consensus mechanisms and sharding techniques to efficiently manage large-scale user traffic. Additionally, implementing formal verification methods would strengthen the correctness and security of smart contracts. Finally, incorporating artificial intelligence and machine learning models could significantly improve document categorization, search functionalities, and personalized recommendations, leading to a more intelligent and efficient system overall.

Limitations and Implications

The proposed framework faces certain limitations that should be acknowledged. Real-time performance is significantly impacted by blockchain transaction latency, which can hinder the system's responsiveness in time-sensitive applications. Additionally, achieving seamless cross-platform integration remains challenging due to differences in blockchain protocols and data handling standards across networks. Furthermore, the framework's reliance on blockchain infrastructure introduces high computational demands, particularly for mining and consensus operations, which can increase resource consumption and operational costs.

Despite these challenges, the framework presents strong practical implications. It offers a viable solution for secure digital identity management and document sharing by leveraging the immutability and transparency of blockchain technology. Moreover, this work contributes to the growing domain of decentralized applications by illustrating how blockchain can effectively enhance data integrity and security. These findings pave the way for further advancements in the development of robust, decentralized data management systems.

Conclusion

In conclusion, the paper presents a compelling alternative to conventional paper-based document storage and management systems. Its inherent advantages, such as enhanced security and convenience, offer individuals a reliable means to store and access critical documents online, mitigating the risks of loss or damage associated with physical records. It focuses to prove its worth by streamlining access to essential documents like educational certificates and driver's licenses, significantly reducing time and effort. Furthermore, DB-smart's eco-conscious approach aligns with sustainable practices, contributing to a greener environment by reducing paper usage. Looking ahead, further enhancements, such as integration with other platforms like AI powered document categorization, cross border document verification, decentralized identity management, blockchain integration for added security, multilingual support, and the potential inclusion of augmented reality features, promise to elevate the paper's user-friendliness and robustness, making it an even more compelling solution for modern document management needs.

Authors Contributions

All the authors have equally contributed for the research.

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