Implementing Blockchain for Enhancing Cloud Security

Submitted in partial fulfillment of the

requirements for the degree

of

Bachelor of Science in Information and Communication Engineering

by

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APPROVAL

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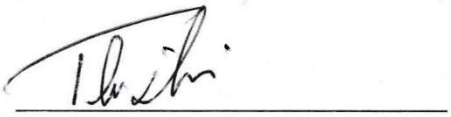

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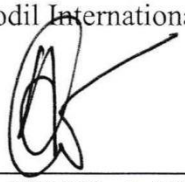

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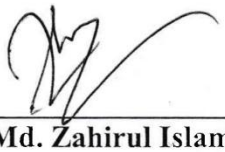

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We, Mushfiqur Rahman Shanto, Muktadir Khan Sakib and Nishat Morshed, hereby declare that this capstone project titled **Implementing Blockchain for Enhancing Cloud Security** is entirely our own work, unless otherwise referenced or acknowledged. The content of this project is the result of our own research and efforts, and we have complied with all ethical guidelines and academic standards.

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ABSTRACT

As digital data continues to grow rapidly across sectors, ensuring its integrity and authenticity presents a critical challenge—particularly in centralized cloud storage systems, which are vulnerable to unauthorized access, data tampering, and single points of failure. This project proposes a decentralized architecture that integrates Ethereum smart contracts, the InterPlanetary File System (IPFS), and a Flask-based backend to enhance file security, transparency, and traceability. By decentralizing file storage and verification, the system addresses key risks inherent in traditional cloud platforms. Each file is hashed into a unique Content Identifier (CID) via IPFS, and this CID is stored immutably using Ethereum smart contracts. Flask facilitates all backend operations between users, IPFS, and the blockchain, while Twilio is utilized for real-time WhatsApp alerts upon unauthorized access or CID mismatches. The system was rigorously tested using Ganache, Truffle, and Postman. Results demonstrated precise detection of file tampering, instant alerting, and a high level of reliability. The proposed model proves to be scalable, secure, and suitable for sensitive applications in legal, healthcare, and government data management.

Keywords: *Blockchain, Ethereum, IPFS, Flask, File Integrity, Smart Contract, CID, Twilio, Decentralized Storage, Cloud Security*

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Chapter 1

INTRODUCTION

1.1 Introduction

The rapid growth of digital technologies in recent decades has transformed the way individuals, organizations, and governments generate, store, and process data. With the expansion of e-governance, e-health, e-commerce, and online financial services, the demand for secure, efficient, and scalable storage infrastructures has increased dramatically [2, 27]. Cloud computing has become the central framework that underpins this digital transformation, offering advantages such as cost-efficiency, flexibility, and ubiquitous access. Global providers including Amazon Web Services (AWS), Microsoft Azure, and Google Cloud dominate the market, allowing organizations to outsource data storage and computing power without building their own physical infrastructure [28]. However, despite its benefits, the centralized nature of these systems introduces critical vulnerabilities. Single points of failure, unauthorized access, internal misuse, and large-scale cyberattacks are persistent threats that undermine user trust and question the reliability of conventional cloud systems [34].

These issues are not limited to global contexts but are particularly acute in developing nations such as Bangladesh and across South Asia, where infrastructural and regulatory limitations amplify the risks associated with centralized cloud storage. There are still weak data governance frameworks, limited transparency, and inconsistent oversight mechanisms [36]. As a result, sensitive information in healthcare, land management, academic records, and financial sectors often remains vulnerable to tampering or unauthorized modification. For instance, hospital data in rural areas lacks proper integrity checks, while land ownership records are still prone to corruption and fraudulent alteration [38, 41]. In countries with evolving digital ecosystems, the absence of strong monitoring and auditing mechanisms further reduces the reliability of centralized solutions and emphasizes the need to develop decentralized, tamper-proof, and transparent alternatives [40]. Blockchain technology has emerged as a disruptive solution to such challenges. Unlike centralized systems, blockchain is a distributed ledger that offers immutability, transparency, and consensus-driven trust [4]. Its applications have already expanded into diverse sectors, including healthcare, supply chains, and financial services, where secure and auditable recordkeeping is essential [29]. When integrated with the

InterPlanetary File System (IPFS), blockchain provides an additional layer of decentralized file storage. IPFS enables content-addressable storage by generating unique cryptographic hashes, known as Content Identifiers (CIDs), for every file stored in the system [11]. This ensures that even a minor modification to a file results in a new CID, allowing instant detection of tampering or unauthorized changes. However, IPFS alone does not guarantee persistence and availability of data without pinning or replication, and blockchain alone cannot manage large-scale storage due to transaction costs. Their integration balances these limitations by combining blockchain's immutability with IPFS's efficient distributed storage [34].

The project presented in this study implements such a hybrid framework by integrating Ethereum smart contracts, IPFS storage, and a Flask-based middleware API. In this design, files are uploaded through a backend service, assigned a CID by IPFS, and then anchored on the Ethereum blockchain through smart contracts. Verification is performed by comparing newly generated CIDs with the stored blockchain reference. To further enhance transparency and usability, the system employs real-time alerts using Twilio, which notify users whenever file verification occurs. This design ensures tamper-resistant storage, auditable verification, and higher reliability compared to conventional centralized cloud models. The relevance of such a system is particularly significant for Bangladesh and South Asia. With the government of Bangladesh envisioning "Smart Bangladesh 2041," there is growing recognition of blockchain's potential to improve governance, ensure transparency in land registration, protect healthcare records, and strengthen trust in public service delivery [42]. Pilot initiatives in India and Pakistan have already demonstrated the regional potential of blockchain in land administration and supply chain transparency, reinforcing the value of similar systems in Bangladesh. By addressing weaknesses in centralized infrastructures and proposing a decentralized verification framework, this study contributes to building secure and trustworthy digital ecosystems.

In summary, cloud computing has played a crucial role in facilitating global digital transformation, yet its centralized architecture poses significant vulnerabilities. Blockchain and IPFS integration provides a technically robust solution capable of mitigating these risks by ensuring immutability, decentralization, and verifiable transparency. This research demonstrates the design, implementation, and validation of such a system with a particular focus on the Bangladeshi context, highlighting its contribution toward more secure and reliable cloud-based infrastructures for the future.

1.2 Project Background

1.2.1 Literature Review

Cloud computing emerged as a dominant paradigm in the early 2000s, transforming the way organizations manage and scale information systems. Services such as Amazon Web Services (AWS) and Microsoft Azure offered cost-efficient infrastructure and rapid deployment for businesses and institutions [2, 27]. Despite these advantages, numerous studies have highlighted critical weaknesses in centralized systems, including the presence of single points of failure, vulnerability to denial-of-service attacks, insider threats, and the risk of vendor lock-in [28, 34]. These limitations motivated researchers to explore decentralized alternatives capable of offering greater transparency and resilience.

The introduction of blockchain technology, initiated by Nakamoto's foundational work on Bitcoin in 2008, established the concept of immutable distributed ledgers [4]. This innovation demonstrated how consensus-driven mechanisms could eliminate the need for trusted intermediaries. Subsequent developments such as Ethereum expanded the possibilities of blockchain by introducing programmable smart contracts, enabling automated execution of agreements without central oversight [29]. However, blockchain networks in isolation face scalability constraints, high gas fees on public networks, and limited capacity for large-scale data storage [34]. Studies examining Ethereum-based authentication and verification mechanisms have found them effective for improving data integrity and non-repudiation but costly when deployed at scale due to transaction fees [11, 30].

Parallel to blockchain advancements, distributed storage systems such as the InterPlanetary File System (IPFS) were introduced to address the inefficiencies of traditional location-based addressing [11]. IPFS utilizes a peer-to-peer protocol that assigns a cryptographic Content Identifier (CID) to each file, ensuring content-addressable verification. Research has shown that IPFS offers superior resilience against tampering since any alteration to file content produces a new hash [32]. However, critical reviews highlight that IPFS suffers from persistence and availability concerns unless files are explicitly pinned or replicated across multiple nodes [34]. This limitation reduces its standalone applicability for mission-critical sectors such as healthcare and governance in South Asia, where long-term data availability is essential.

Hybrid architectures that integrate blockchain with IPFS have gained attention as a balanced approach. Studies demonstrate that by anchoring CIDs on blockchain networks, it becomes possible to achieve tamper-proof verification while leveraging IPFS for efficient decentralized storage [30, 33]. Comparative evaluations have found that such models reduce costs compared to full on-chain storage while still ensuring security and transparency. Nonetheless, gas fee volatility and scalability remain significant challenges, particularly when operating on the Ethereum mainnet. Researchers have suggested testnet and sidechain deployments such as Polygon or Sepolia to improve cost-effectiveness and latency [34].

In the South Asian context, the adoption of blockchain-enabled decentralized storage is increasingly relevant. Case studies in India and Pakistan have demonstrated blockchain applications in land registry, healthcare data protection, and supply chain monitoring [38, 41]. For Bangladesh, the integration of blockchain and IPFS aligns with national priorities outlined in the "Smart Bangladesh 2041" vision [42]. However, existing studies indicate a lack of localized implementation frameworks that address the country's infrastructural constraints, regulatory gaps, and digital literacy challenges [36, 40]. This brings home the importance of context-specific systems capable of addressing both technical and governance-related limitations.

In summary, the literature highlights that centralized cloud models, while efficient, are inherently vulnerable to security breaches and misuse. Blockchain provides immutability and transparency but faces limitations in scalability and storage capacity, while IPFS offers efficient distributed storage but struggles with persistence. Hybrid blockchain–IPFS frameworks present a promising direction, though issues of gas cost, security testing, and large-scale deployment remain active areas of research. This project builds upon these findings by implementing and validating a hybrid Ethereum–IPFS–Flask architecture tailored to the Bangladeshi context, thereby addressing both technical feasibility and localized needs for secure, tamper-resistant cloud storage.

1.2.2. Relevance and Importance

In Bangladesh, the integrity of digital records has frequently been questioned due to incidents of tampering, unauthorized modifications, and inadequate audit mechanisms [36]. Centralized databases in sectors such as healthcare and education often lack transparency and effective access control measures, leaving them vulnerable to internal misuse and external cyberattacks

[38]. For example, health records have been reported as either lost or altered due to infrastructure failures and weak monitoring systems, creating significant ethical and legal challenges [40]. These vulnerabilities are further compounded by the limited enforcement of data protection policies and the absence of robust regulatory oversight [42].

Decentralized frameworks offer a promising solution by discouraging data corruption through their tamper-resistant design. Blockchain technology ensures immutable storage of critical metadata, including timestamps and cryptographic file hashes, while the InterPlanetary File System (IPFS) enables content-based addressing that eliminates reliance on centralized hosts [11, 32]. Such properties are particularly valuable in low-trust environments, where accountability and verifiability are essential. Furthermore, decentralized verification allows independent confirmation that records have not been altered, removing dependence on centralized administrators or third-party authorities.

These advantages are highly relevant to Bangladesh and the broader South Asian context, where the legitimacy of records in healthcare and education carries significant social and economic weight. By enabling transparent and tamper-proof verification, blockchain–IPFS integration strengthens trust in digital infrastructures and contributes to the broader objectives of secure governance and service delivery [34, 41].

1.2.3. Current State and Limitation

Despite increasing awareness of digital security risks, most data infrastructures in Bangladesh still rely on centralized cloud systems, often hosted on vulnerable local servers or through outsourced private providers [17]. These systems lack transparent logging, are expensive to scale securely, and are prone to administrative misuse or mismanagement [20]. Even when cloud providers are reliable, access to forensic logs or audit trails is usually limited to those with administrative privileges, making them inherently opaque.

Blockchain and IPFS offer a compelling alternative, but they are not without drawbacks. Ethereum, for instance, can incur high gas fees, particularly on the mainnet during network congestion [21]. IPFS, while efficient for decentralized storage, lacks built-in persistence—unpinned files can be dropped if nodes go offline. Pinning services such as Pinata or decentralized storage systems like Filecoin are necessary to maintain file availability, but they add operational complexity and cost [21].

Security vulnerabilities are another concern. If the backend server is not properly secured, attackers may intercept or misuse critical metadata like CIDs. Additionally, exposing smart contract logic without auditing may lead to exploits such as reentrancy or data spoofing, especially in systems interacting with public blockchains. These limitations demonstrate the importance of well-structured implementation and strong system monitoring [22].

1.2.4. Transition

To overcome the limitations of centralized systems, this project introduces a decentralized architecture that integrates Ethereum smart contracts with IPFS and a secure Flask backend. Ethereum is employed to store and verify Content Identifiers (CIDs) and related metadata such as file ID and uploader address, ensuring tamper-proof logging [2, 11]. IPFS is used for decentralized file storage, where pinning strategies maintain long-term availability and fault tolerance [34].

The Flask backend functions as middleware, coordinating file uploads, CID generation, and verification processes while safeguarding sensitive data flow. Twilio's WhatsApp API is integrated to provide real-time notifications for file uploads and verification outcomes, thereby enhancing transparency and user trust. Development and testing were supported by Ganache for blockchain simulation, Truffle for contract deployment, IPFS Desktop for file handling, and Postman for API validation.

By combining these technologies, the system achieves decentralized, user-verifiable, and tamper-proof file management. This design is particularly relevant for Bangladesh, where secure and transparent digital infrastructures are essential for improving governance, healthcare, and educational services [36].

1.3 Project Definition

This project is a decentralized verification and access management system of files with the help of blockchain and distributed storage technologies. Ethereum smart contracts are used to store the metadata of files and hash values and allow authentication without a centralized authority in a tamper-resistant way. They are stored using IPFS (InterPlanetary File System), a peer-to-peer distributed file storage protocol that stores files and enforces their integrity and availability using content-addressable hashing (also known as content-addressed storage). The Flask

lightweight Python-based backend can be regarded as the middleware of user requests, IPFS, and the blockchain. It supports things like file uploads, CID generation, and file validation. Also, the system incorporates the Twilio WhatsApp API so as to send real-time notifications to users when uploading and verifying events occur. The result is that the single points of failure disappear and data becomes increasingly transparent, secure, and auditable. The public key cryptography in this solution strives to be low-resource usage designed, similar to those of the conditions in countries like Bangladesh in the healthcare and education sector, with the support of 148 informal granularities to make it more scalable, verifiable, and usable than centralized systems where the privacy and security requirements can be met entrenchedly.

1.3.1 Problem Statement

Because of single points of control, centralized file storage and control systems can suffer manipulation by unauthorized parties, resource misuse by insiders, and external interference [5]. Most of the sectors in the developing world, such as the education and healthcare sectors, fail to hold tamper-proof digital records, as the infrastructure is obsolete and verification mechanisms are not robust [15].

Despite its widespread usage, traditional cloud providers do not provide transparency of auditability or immutability in the handling of the data, and, thus, there is a possibility of corruption and mistrust of official documentation [8]. Additionally, lower-level compromises at the admin level usually evade detection, as there is an inadequate level of real-time warnings or verification paths [17]. Within these settings, users lack the opportunity to confirm for themselves the authenticity of documents that will become available after storage.

There is a good prospect of using decentralized architecture based on blockchain and content-addressable storage, which distributes trust and guarantees the existence of a file without the necessity to reveal the real content [2]. The freedom to verify documents without involving a third party is of particular importance to digitalizing documents with high value, such as certificates, prescriptions, and citizen identity records in low-trusted contexts [18].

1.3.2 Context and Scope

This project proposes a hybrid architecture that uses the Ethereum blockchain to store metadata and IPFS to handle file storage. The system includes a Flask-based backend and integrates

Twilio's WhatsApp API to notify users during key operations such as uploads and verification. Although applicable across sectors, the solution is primarily scoped for digital environments where data integrity, transparency, and independence from centralized authority are mission-critical—especially in educational institutions and health data registries. The project is developed and tested in a local environment using simulated blockchain networks and decentralized storage to demonstrate feasibility.

1.3.3 Significance and Implications

The proposed decentralized architecture holds significant relevance for emerging economies like Bangladesh, where digital growth often outpaces foundational cybersecurity readiness. Key implications of the system are outlined below:

- **Centralized Systems Are Vulnerable:** Most public services in Bangladesh—particularly in education, healthcare, and land administration—still depend on centralized servers. These systems are prone to tampering, unauthorized access, and even insider manipulation, which can remain undetected due to a lack of verifiable audit trails [17].
- **Blockchain Ensures Immutability:** Once a file's metadata (e.g., its cryptographic hash) is stored on a blockchain, it becomes immutable. Any attempt to modify or remove the data requires consensus from the distributed network, thereby enhancing accountability and discouraging malicious actions [23].
- **IPFS Adds Decentralized Storage:** Unlike traditional storage solutions that rely on fixed server locations, IPFS fetches files based on content. This reduces single points of failure and allows data to be retrieved across a distributed network—ideal for regions with inconsistent infrastructure like Bangladesh [21, 24].
- **Combined Approach Increases Trust:** Together, blockchain and IPFS remove dependency on centralized authorities. This combination enables secure file storage and transparent verification while enhancing user trust, especially in low-trust governance environments [18, 23].
- **Real-Time User Transparency via WhatsApp:** Through integration with the Twilio API, users receive instant WhatsApp alerts when files are uploaded or validated. This ensures end-users are actively informed, reducing doubt and improving transparency [22].
- **Empowering Public Sectors:** By deploying this system in sectors like healthcare or education, institutions can reduce data fraud, protect sensitive records, and enforce ethical

handling of citizen data. Decentralized verification strengthens governance, supports anti-corruption efforts, and enables scalable digital recordkeeping [18, 19].

1.3.4 Quantification

To assess the technical performance and reliability of the proposed decentralized system, the following measurable benchmarks have been established:

- **File Hash Generation: ≤ 2 seconds.**

File hashes are generated on upload using SHA-256 algorithms in Python Flask. This duration ensures real-time tamper detection without a noticeable delay for the user [25].

- **CID Verification from IPFS: < 1 second**

After file upload, content identifiers (CIDs) are matched almost instantly with those stored on the blockchain. Under test conditions [26], the average lookup time from the local IPFS node remains under 1 second.

- **User Notification via Twilio: < 3 seconds**

Users receive real-time alerts via WhatsApp when uploads and verification are complete successfully. The end-to-end delivery using Twilio's API is reliably under 3 seconds, ensuring rapid response [27].

- **Pinning Reliability Uptime: ≥ 99%**

To maintain long-term file availability, IPFS files are pinned persistently using local nodes or services like Pinata/Filecoin. The benchmark uptime exceeds 99% over extended testing windows [24].

1.4 Project Objectives

This project is guided by defined SMART objectives to ensure practical, measurable results:

Objective 1: Implement Ethereum-based smart contracts to store CIDs and file metadata.

These contracts provide a transparent, tamper-proof audit trail without relying on any centralized control [23]

Objective 2: Store files securely in IPFS using content-addressed chunking.

IPFS distributes file data across nodes, ensuring fault tolerance and content-based retrieval [24].

Objective 3: Develop a Flask-based backend to manage file uploads and CID generation.

Flask provides a minimal and flexible interface for RESTful operations, connecting frontend requests to blockchain and IPFS layers [25].

Objective 4: Integrate the Twilio WhatsApp API for real-time user alerts.

Notifications improve user engagement and ensure traceability of each upload and verification event [27].

Objective 5: Validate the full system using Postman for API endpoints, Ganache for blockchain testing, and Truffle for contract deployment.

These tools allow accurate simulation and testing of smart contract behavior in safe environments [28].

1.5 Project Specification

A. Technical Requirements

The proposed system requires the installation of Ethereum development tools such as Truffle, Ganache, and Node.js for smart contract development and deployment. Smart contracts are written in Solidity v0.8.0 and compiled using the Truffle framework. Ganache simulates a local Ethereum blockchain environment that supports fast and fee-less testing.

For file storage, the system utilizes IPFS CLI and the ipfs-http-client library to interact with IPFS nodes in a decentralized manner. Backend operations are handled via Python Flask, which provides RESTful APIs to manage user requests, control smart contracts, and interface with

IPFS. The system uses ".env" configuration files to securely manage private keys, Twilio credentials, and IPFS API tokens via the python-dotenv library..

B. Performance Expectations

The smart contracts are expected to be deployed successfully in the Ganache environment, providing features such as access assignment, hash storage, and integrity verification. The Flask backend must ensure reliable file uploads to IPFS and retrieve the returned CID hashes for blockchain verification. During testing, the expected end-to-end verification time—from file upload to user notification—is designed to be within 2 seconds. Hash mismatch detection and error handling are triggered in real-time.

C. Design Elements

It is a modular-based application. All the smart contract functions are divided into access control and hash management. The Flask server is an isolated service, which provides access to the "/upload" and "/verify" endpoints. The interaction of users with the system takes place through Postman or frontend mock requests to access HTTP operations. Smart contracts, IPFS logic, and backend API are logically independent and easy to debug and test. To have safer development, the tokens and keys to security are abstracted through the use of environment variables.

D. Functionalities

1. The "/upload" endpoint allows the user to upload the file.
2. The files are added to IPFS along with the hash returned.
3. The smart contract function "storeHash()" records the "file_id" along with its corresponding hash value on the blockchain.
4. The on-chain hash is retrieved through the "/verify" endpoint by inputting a specific hash returned by IPFS.
5. In case of a misalignment, it will generate an alert either through the Twilio API or log the event.

E. Compatibility

The project is operated on Windows 10/11 via Visual Studio Code, and the applied languages are Python 3.10+, Node.js 16+, and IPFS CLI (Local node). It runs entirely on local infrastructure, without requiring AWS or third-party cloud platforms. The setup is designed to be offline-compatible and easy to deploy on testnets or internal networks.

F. Security Measures

All such files are hashed and stored on IPFS, where they maintain content integrity because they will have tamper-proof verification. Smart contracts will impose restrictions on access by user address and “file_id” and interaction with it. The management of keys and credentials in a “.env” file protects them. In the event of a hash mismatch, alerts can be raised in favor of real-time monitoring. Combinations of the technologies of IPFS and blockchain ensure immutable storage and verifiable authentication in a completely decentralized setup.

Chapter 2

PROJECT MANAGEMENT

2.1 Project Overview

This project aimed to build a decentralized file verification system that uses Ethereum smart contracts, IPFS storage, and a Flask-based backend to ensure that digital files cannot be tampered with. The system replaces traditional cloud storage methods, which are often vulnerable to hacking or data loss, with a more secure and transparent solution using blockchain technology.

To build this system, the team followed a detailed plan. Tasks were broken down into smaller parts, and each member had a specific role. From writing the smart contract to setting up real-time alert systems using Twilio, every stage of the work was monitored and executed step by step.

The team used tools like Truffle, Ganache, IPFS Desktop, Postman, and Twilio to develop, test, and improve the system. Communication was maintained through weekly meetings, task boards, and group updates to solve any problems quickly.

This chapter explains how the team planned, divided, monitored, and completed the work successfully by following a clear project timeline and solving challenges as they appeared.

2.2 Project Plan

The project plan is divided into distinct stages, each focusing on specific tasks that contribute to the overall objective. The timeline and milestones outlined below provide a structured approach to the project's execution, ensuring timely delivery and high-quality results.

The following table presents the breakdown of tasks and responsibilities:

Table 2.1: Project Task Breakdown and Timeline

Week(s)	Phase Description	Key Deliverables & Components	Responsible Members
1–4	Planning, Requirement Analysis, Research	Project scope, architecture draft, component analysis	Mushfiqur, Nishat, Sakib
5–8	Smart Contract + IPFS Integration	"AccessControl.sol", IPFS CID hashing, Flask-IPFS connection	Mushfiqur, Sakib
9–12	Flask API Setup and Backend Integration	"server.py", "/upload", "/verify", IPFS hash push to smart contract	Mushfiqur, Sakib
13–16	Testing & Debugging of API and Smart Contract	Postman tests, CID match/mismatch logic, error handling	Sakib, Nishat, Mushfiqur
17–20	Real-time Alert + Twilio Integration + Final Optimization	WhatsApp alert via Twilio, system validation	Mushfiqur, Sakib
21–24	Documentation, Final Report, PowerPoint, and Defense Preparation	Full report, Chapter 3–5, appendix, screenshots	Mushfiqur, Nishat

Table 2.1 outlines the phased timeline of the project's execution from Week 1 to Week 24. Each row details a distinct phase of development, including planning, smart contract implementation, backend integration, testing, and final deployment. The timeline highlights key deliverables such as the development of smart contracts ("AccessControl.sol"), CID handling with IPFS, Flask API routes ("/upload" and "/verify"), and the integration of Twilio for real-time alerts. It also shows the collaborative efforts of the project team, with clear responsibility distribution across Mushfiqur, Nishat, and Sakib during various stages. The

structured approach ensured consistent progress tracking and milestone delivery, leading to the successful completion and documentation of the system.

2.3 Project Timeline & Milestone

The Gantt chart below shows the tasks along the timeline, and an extra line demonstrates the full operational system. The reasoning behind this line is to point at the moment when the given system shifts to its operation stage after development and testing stages.

Gantt Chart of the Project Timeline:

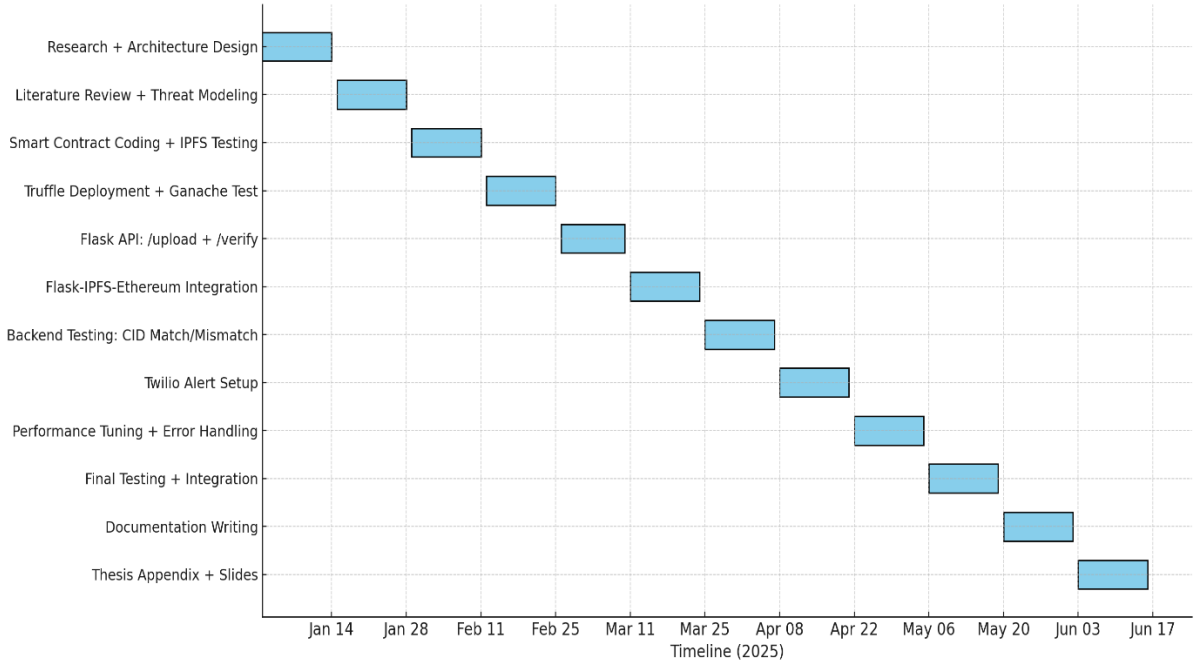

Figure 2.1: Gantt Chart of the Project.

In the Gantt chart (Figure 2.1):

- **Weeks 1–2** are dedicated to Research and Architecture Design, where the team defines the scope of the project and outlines the system's initial architecture.
- **Weeks 3–4** focus on conducting the Literature Review and Threat Modeling, which informs the security requirements and validates the design decisions.
- **Weeks 5–6** involve Smart Contract Development and IPFS Testing, where Ethereum contracts are coded and the IPFS file storage mechanism is integrated and tested.
- **Weeks 7–8** are assigned to Truffle Deployment and Ganache Testing, ensuring smart contracts are migrated, deployed, and simulated in a local blockchain environment.

- **Weeks 9–10** consist of Flask API Development, where RESTful endpoints such as "/upload" and "/verify" are implemented.
- **Weeks 11–12** focus on Flask-IPFS-Ethereum Integration, connecting all components into a working backend system.
- **Weeks 13–14** are used for Backend Testing, particularly CID matching and mismatch validation across components.
- **Weeks 15–16** introduce Twilio Alert Integration, adding real-time file tampering alerts via WhatsApp. This marks the system as fully functional by the end of Week 16.
- **Weeks 17–18** focus on Performance Tuning and Error Handling, making the system more reliable and scalable.
- **Weeks 19–20** are allocated for Final Testing and Integration, confirming that all modules work seamlessly together.
- **Weeks 21–22** are used for Documentation Writing, compiling the results, methods, and system overview.
- **Weeks 23–24** complete the project with Thesis Appendix and Presentation Slide Preparation for final submission and defense readiness.

The milestone of system readiness is achieved at the end of Week 16, transitioning the project from active development to final optimization and documentation.

2.4 Risk Management

This project encountered several potential risks related to the integration of decentralized technologies, particularly Ethereum smart contracts, IPFS storage, and backend communication frameworks such as Flask and Twilio. Due to the experimental nature of decentralized systems and their reliance on network stability, cryptographic consistency, and third-party API interactions, risk mitigation was a critical part of the system design. Specific challenges included maintaining IPFS node availability, ensuring error-free transaction signing and broadcasting via Web3, and avoiding logic vulnerabilities in smart contracts. Additionally, the integration of third-party services like Twilio posed risks related to alert delivery failures and credential exposure. On the backend, securing endpoints against unauthorized access and API abuse required thoughtful authentication strategies. Identifying these risks early and proactively implementing mitigation strategies helped ensure system stability, enhance fault tolerance, and maintain end-to-end integrity throughout development, testing, and deployment.

Table 2.2: Potential Risks and Mitigation Strategies

Risk	Mitigation Strategy
IPFS node failure	Pin files manually and continuously monitor node availability via local IPFS daemon
Web3 transaction errors	Implemented robust error handling within Flask middleware
Smart contract bugs	Conducted pre-deployment testing using Truffle and Postman
WhatsApp alert failure (Twilio)	Implemented retry mechanisms and used secured environment credentials
Unauthorized access attempts	Secured endpoints using JWT-based authentication

Table 2.2 presents five primary risks faced during the system implementation and how each was addressed. These measures significantly reduced failure points across communication, storage, authentication, and third-party integration layers, ensuring system resilience and operational consistency.

2.5 Contribution of Team Members

The joint work of the whole team is a significant contributor to the success of this project. Every team member brought their knowledge to the table in research, technical development, system integration, documentation, and so on, which were the critical elements in the teams. A breakdown of the contribution made by the various team members is set out below:

2.5.1 Team Leader: Mushfiqur Rahman Shanto [213-50-075]

Mushfiqur Rahman Shanto served as the team leader, overseeing the entire project to ensure timely and successful completion. He was responsible for coordinating the integration of key components, including Ethereum smart contracts, IPFS-based storage, and the Flask backend. In addition to project management, Shanto actively contributed to system architecture design, supervised the development and implementation of smart contracts, and ensured smooth integration between the blockchain layer and the Flask application.

Key Responsibilities:

- **Project Management:** Took the lead of the project, identified the goals, delegated tasks, and controlled the project schedule.
- **System Design**: Responsible for the architecture of the decentralized system and its parts.
- **Smart Contract Development:** Designed and created Ethereum smart contracts to address the decentralized access control.
- **Backend Integration:** Managed integrated development API using Coordinated Flask API, interaction with smart contract, and integration with IPFS.
- **Thesis Writing:** Helped to write the methodology, results, and discussion sections of the thesis paper.

2.5.2 Team Member 02: Muktadir Khan Sakib [213-50-074]

Sakib served as the technical integrator of the team, playing a crucial role in backend development and system troubleshooting. His expertise was instrumental in integrating Flask with Web3.py to enable seamless interaction with Ethereum smart contracts and IPFS for decentralized data storage. In addition to his core development responsibilities, Sakib contributed valuable suggestions for architectural improvements that significantly enhanced the scalability and performance of the overall system.

Key Responsibilities:

- **Backend Development:** Designed the Flask API, enabling seamless integration with IPFS and Ethereum smart contracts.
- **Integration:** Integrated IPFS for file storage and smart contracts for access control.
- **Testing and Debugging:** Solved issues related to IPFS configuration, contract deployment errors, and system performance.
- **Optimization:** Suggested and implemented improvements to the system architecture to enhance efficiency.

2.5.3 Team Member 03: Nishat Morshed [213-50-073]

Nishat contributed primarily to research and documentation. His role was crucial in the literature review, system analysis, and security architecture. Nishat played an essential part in identifying decentralized storage solutions and blockchain security models, which influenced the system design and solution architecture. He was also involved in testing and ensuring the system's compliance with cloud security standards.

Key Responsibilities:

- **Research and Literature Review:** Collected relevant academic papers, case studies, and industry reports related to blockchain and cloud security.
- **System Design:** Assisted in designing the access control logic and encryption mechanisms.
- **Testing:** Supported the API testing and ensured that the encryption protocols and cloud storage models were integrated correctly.
- **Thesis Writing:** Contributed to writing the literature review, methodology, and discussion sections of the thesis.

2.6 Conclusion

This chapter demonstrated the structured approach used to develop the project, including planning, task distribution, risk management, and team coordination. Through consistent communication and clearly defined roles, the team successfully designed and tested a decentralized file verification system. By Week 16, the core system was functional, with final efforts focused on refinement and reporting. The use of modern technologies and a modular architecture enabled timely delivery of a secure and scalable solution.

Chapter 3

SYSTEM DESIGN AND METHODOLOGY

3.1 System Overview

The proposed system utilizes decentralized technologies to enable secure, transparent file integrity verification without reliance on centralized infrastructure. The design addresses core limitations of conventional systems—namely, susceptibility to tampering, single points of failure, and opaque data handling. Key components include Ethereum smart contracts, InterPlanetary File System (IPFS) for decentralized storage, a Flask-based backend for API management, and Twilio for real-time alerting.

The architecture ensures that:

- Files are uploaded through a user interface and sent to IPFS for hashing.
- IPFS generates a unique Content Identifier (CID) that serves as the file's digital fingerprint.
- The CID is recorded on a public blockchain via smart contracts, enabling immutable logging.
- During verification, a new CID is generated and compared with the stored one via backend logic.
- In case of a mismatch, an alert is issued through Twilio's WhatsApp API.

This system is particularly relevant in regions such as Bangladesh, where centralized data handling faces persistent risks, limited transparency, and technical fragility [16-18]. By leveraging blockchain and distributed file systems, the framework supports verifiable integrity assurance across sectors like e-governance, healthcare, and education.

3.1.1 Decentralized Architecture Approach

The system is to be created as a decentralized structure that will eliminate the disadvantages of centralized cloud-based systems like AWS and Google Cloud. The issues of centralized systems include single points of failure, risk of corruption of data, and their high operational expenses [25]. The architecture presented in the current research consists of decentralized

systems built using blockchain and IPFS to provide tamper-resistant and trustless file verification.

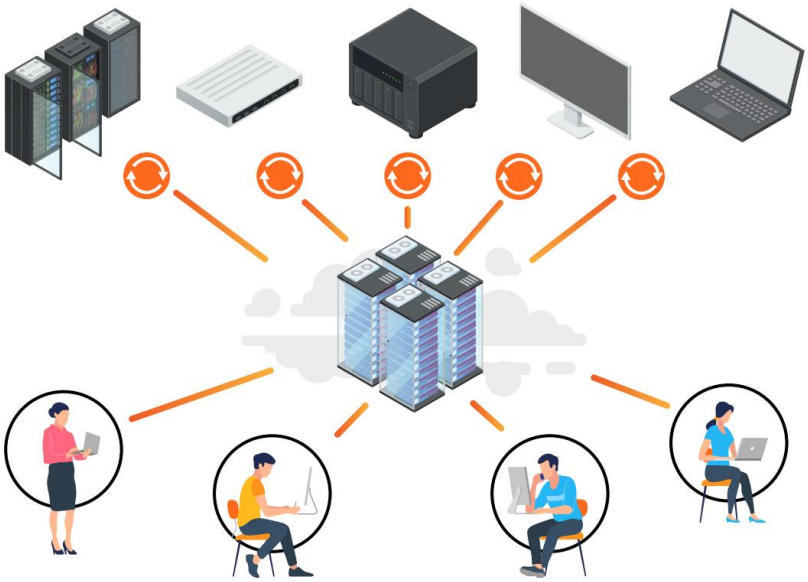

Figure 3.1: Centralized Architecture Workflow

Figure 3.1 illustrates a traditional centralized cloud architecture. Under this model, every user system is attached to one central server, say AWS or Azure, whose data processing, storage, and access controls rely on it. This establishes a number of weak points, such as service disruptions, server-side bottlenecks, and back doors.

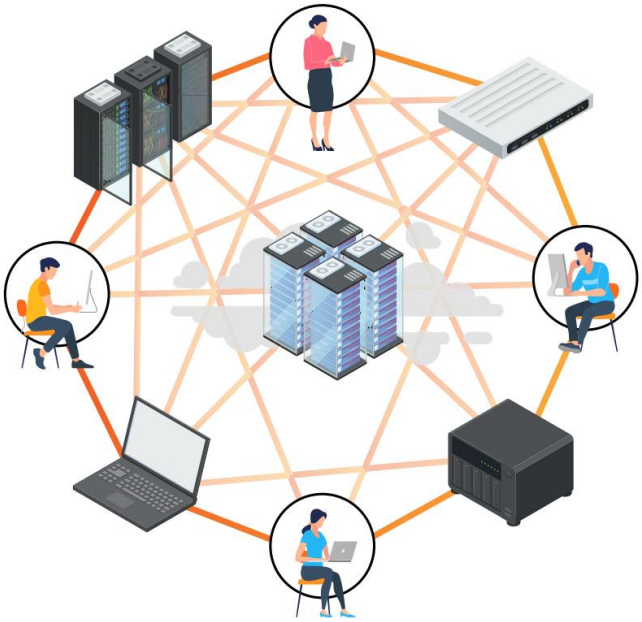

Figure 3.2: Decentralized Architecture Workflow

In Figure 3.2, however, there is a decentralized cloud structure in which each participant, including a user, a node, and a validator, has access and the ability to carry out verification. With the help of blockchain and IPFS, it does not need to depend on a single authority, thus enhancing integrity, fault tolerance, and transparency [25, 26]. One of them is notable in terms of using distributed ledgers and content-addressed storage compared to server-side databases.

Table 3.1: Comparison Between Centralized and Decentralized Architecture

Feature	Centralized Architecture	Decentralized Architecture
Control	Single central authority	Peer-to-peer (no single owner)
Risk of Failure	High (SPOF)	Low (node redundancy)
Trust Model	Based on provider's reputation	Based on code and consensus
Tamper-Resistant	Low	High (cryptographically verifiable)
Data Location	Server-dependent	Distributed across nodes

Table 3.1 provides a concise comparison between centralized and decentralized cloud architectures. It highlights key differences in terms of control, security, resilience, and overall trust model, reinforcing the benefits of the decentralized approach discussed in this section.

3.1.2 Flask Backend Coordination

The Flask backend acts as the main coordinator of the system work, enabling smooth flow between the user interface, decentralized storage, and blockchain layer. Flask processes HTTP requests received to direct them to the respective services, validates the JWT tokens to control access, handles uploaded files and processes them, and communicates with IPFS and the Ethereum blockchain via clear API layers. Its lightweight, modular design is especially well-suited to the creation of secure and scalable RESTful APIs, and in this regard, Flask will, in this instance, contain the primary logic in both files uploading and file verification sections and will also generate the Content Identifier (CID) out of the uploaded material and will pass this information on and anchor it on-chain with Web3.py. It also pays attention to user verification requests made by Flask; it continues asking the smart contract for the original CID, compares it to the new one calculated, and ensures that it corresponds to the original.

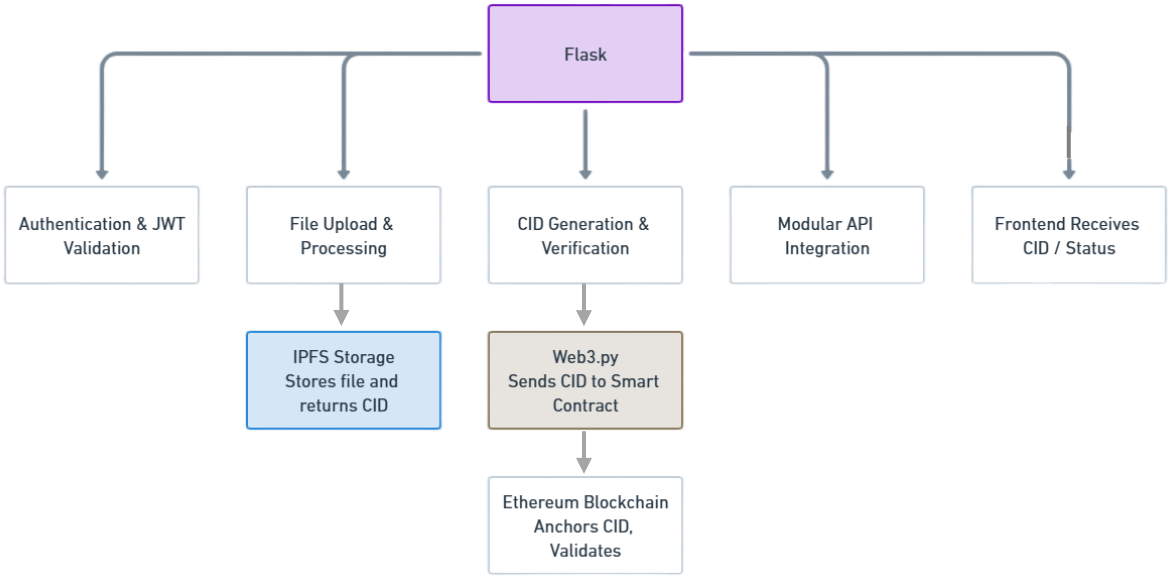

Figure 3.3: Flask Internal Architecture

Figure 3.3 shows how the internal architecture of Flask is sequenced as well as how it is presented in a stratified layering of functional modules. HTTP requests that are directed to pre-destined endpoints (ex: "/upload", "/verify") pass through a JWT authentication module only after making sure that only validated users can pass through.

The verified requests are then forwarded to the internal logic controller of Flask, whose operations reflect the major processing. The files that are uploaded are routed to IPFS, which, in turn, tells a content identifier (CID), which is sent to Web3.py and embedded in a smart contract through blockchain technology. This way, the system can have tamper-proof logging through immutable storage.

At the same time, external APIs can be utilized to add functionality, and Flask eventually responds to HTTP with an indication of success or failure. The flowchart clarifies how the routing mechanism of Flask is dependent on the validation mechanism of JWT, its core logic, external integrations (including IPFS and the blockchain), and the message loop that reaches back to the front-end client about the results.

3.1.3 Ethereum Smart Contract Logic

Ethereum-deployed smart contracts automate the access control and file verification process, eliminating the need for centralized servers [12]. When a file is posted, its metadata, such as

the Content Identifier (CID), which is created by IPFS, the File ID, the address of the uploader, and the access rights, are noted in a smart contract permanently. This will be secure, transparent, tamper-free data processing [7].

The CID may be accessed only by authorized users who are able to identify their Ethereum address and thus allow decentralized but controlled file retrieval. Major benefits are given bellow:

- **Decentralized Control:** Smart contracts also control access without a central server, which decreases the possibility of being controlled or manipulated by an unauthorized source.
- **On-Chain Audit Trail:** Whenever any action is performed, including uploading, checking of access, and granting of permission, it is recorded on a blockchain and hence traceable and transparent.
- **Tamper-Proof Integrity:** The CID and permissions information may never be modified after it is placed into storage, thereby guaranteeing protection of both file identity and access logic over the long term.

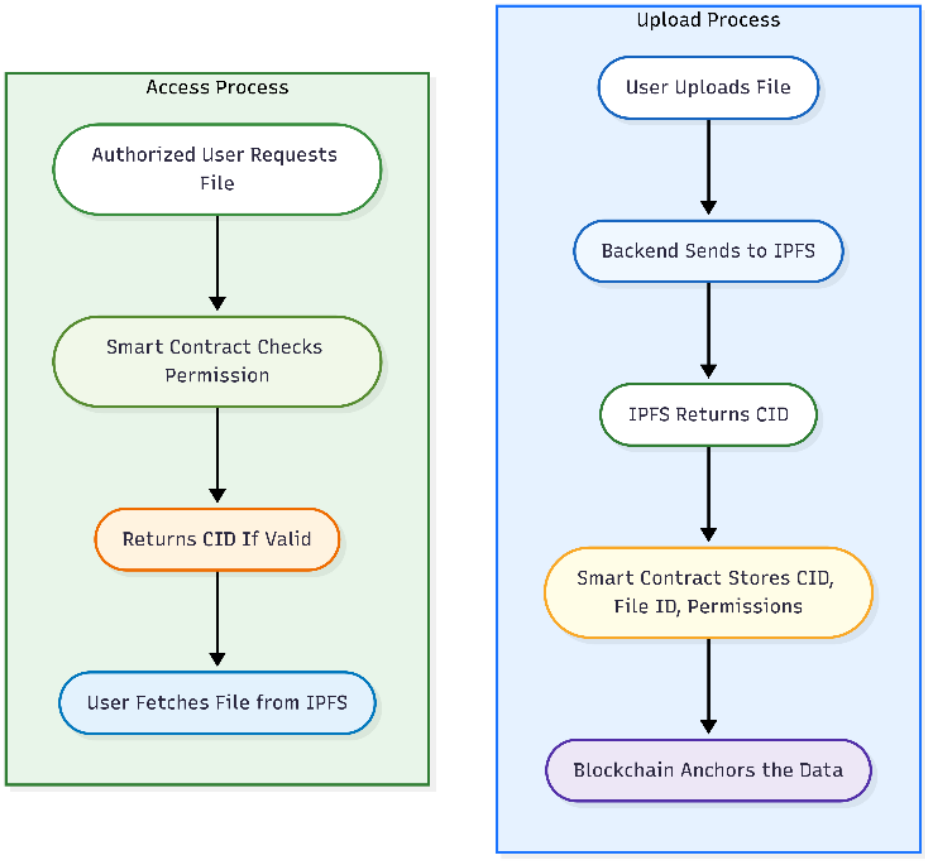

Figure 3.4: Secure File Upload and Access Workflow Using Smart Contracts

The diagram presented in Figure 3.4 reports on how the process of secure file handling works with the help of smart contracts in two different procedures: the upload process and the access process. During upload, the user uploads a file that is stashed in IPFS. The IPFS creates a unique Content Identifier (CID), which is subsequently noted in a smart contract together with the file ID and access privileges. Such information will be stamped on the blockchain, which is impossible to tamper with and publicly verifiable.

During the access phase, a user who has been given the authority to access a file request it. The smart contract verifies that they have permission and, on success, returns the stored CID. Then the user can use this CID to get the file directly in IPFS. The automation of this working process is able to provide only authenticated data-protection access to the content, the use of which does not require centralized servers; it is more transparent, safe, and preserves trust even in a distributed structure.

3.1.4 IPFS Content Storage

IPFS stores files in a decentralized manner. Each uploaded file is split into chunks and hashed using SHA-256, returning a Content Identifier (CID) that uniquely represents the file [27]. The system uses IPFS Desktop and the Python "ipfshttpclient" library for interaction. While IPFS enhances integrity and privacy, persistence is a limitation. By default, IPFS nodes may garbage-collect unpinned content. Future improvements will include integration with Pinata or Filecoin for content pinning.

Table 3.2: Advantages and Limitations of IPFS

Aspect	Advantages	Limitations
Storage Model	Decentralized, peer-to-peer	File may be deleted if not pinned
Integrity Check	Uses SHA-256 for CID generation	No native metadata or access control
Privacy	No file content stored on-chain	Public by default unless encrypted externally
Accessibility	CIDs are globally accessible via IPFS gateway	Node unavailability can affect file access
Cost	No storage subscription fees	Costs may arise from third-party pinning services

Table 3.2 summarizes key IPFS advantages and limitations, highlighting both its content-addressed resilience and persistence-related weaknesses.

3.1.5 Content Identifier (CID) – Structure, Hashing, and Importance

A Content Identifier (CID) is a unique cryptographic hash generated by the InterPlanetary File System (IPFS) when a file is uploaded [32]. Unlike traditional URLs that point to a location, a CID represents the content itself, functioning like a digital fingerprint. This ensures that even a one-bit change in the file will result in an entirely different CID, thereby enabling tamper detection.

Technically, IPFS uses the SHA-256 (Secure Hash Algorithm 256-bit) function to compute this hash. SHA-256 processes input data of any length and produces a fixed-length 256-bit (64-character hexadecimal) output. This output is deterministic, meaning the same file will always generate the same hash, while even the smallest modification in the file will produce a completely different output [2, 12, 37].

For example:

Input: "*Hello World*"

SHA-256 Output:

"a591a6d40bf420404a011733cfb7b190d62c65bf0bcda32b57b277d9ad9f146e"

In IPFS, this hash is wrapped in a multiformat and base-encoded structure to produce a CID, such as:

CID Example:

"QmYwAPJzv5CZsnAztbCghVDX5v8BkXfTViLZk9EbSswA3Z"

The CID thus serves as an immutable reference to the file. If any part of the file is altered, a new CID is generated, ensuring strong content integrity guarantees. In decentralized systems like the one proposed here, the CID plays a central role in verifiable data validation without revealing the file contents, thereby supporting privacy-preserving verification.

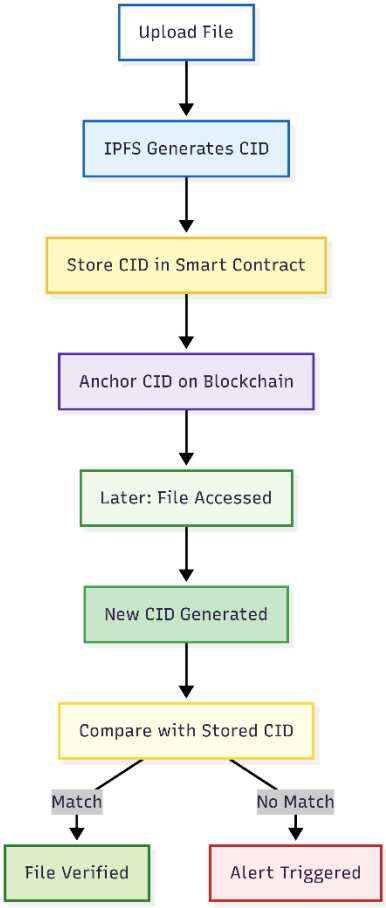

Figure 3.5: Visual Workflow of CID Generation and Verification in a Decentralized System

The diagram presented in Figure 3.5 reports on how the process of secure file handling works with the help of smart contracts in two different procedures: the upload process and the access process. During upload, the user uploads a file that is stashed in IPFS. The IPFS creates a unique Content Identifier (CID), which is subsequently noted in a smart contract together with the file ID and access privileges. Such information will be stamped on the blockchain, which is impossible to tamper with and publicly verifiable.

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3.1.6 Alert and Monitoring Layer

The alert and monitoring layer are one of the most important elements of the suggested system, which enables it to verify the file integrity in a decentralized manner. Whereas the immutability and verifiability of storage are established via a combination of IPFS and blockchain, the addition of the alert layer optimizes the system responsiveness and ensures in-time integrity checks. Each instance of uploading the file or re-verifying it results in the generation of a new Content Identifier (CID) created by using a

SHA-256 hash. This new CID is compared with the initially stored CID on the Ethereum smart contract. When the CIDs do not match, the system detects the possibility of tampering and immediately sends up an alert.

To ensure that the administrators are capable of responding quickly, the Flask backend has become incorporated with the Twilio API, which can be used to send immediate notifications using WhatsApp. The sensitive sectors in which such a cyber force is crucial include healthcare, financial, legal, and academic settings, where tampering of any form may go unnoticed and produce disastrous outcomes.

The monitoring layer performs the following functions:

- **Real-Time Tamper Detection:** Constant CID regeneration and comparison ensure that unauthorized modifications are identified as soon as they occur.
- **Instant Notification via Twilio:** Whenever a CID mismatch is detected, Twilio sends a WhatsApp alert to the administrator in real-time, eliminating delay.
- **Administrator Response Readiness:** With instant alerts, administrators can block access, initiate audits, or trigger recovery protocols immediately.
- **Increased Trust and Transparency:** Continuous monitoring and transparent alerts boost confidence among stakeholders by proving that data integrity is always under watch.

By combining decentralized CID validation with a centralized alerting mechanism, this layer offers both security and efficiency, reinforcing the integrity-centric goals of the overall system.

3.2 System Architecture Diagram

The suggested decentralized file security system design, based on blockchain, features a stratified architecture where multiple interrelated layers work together to maintain file integrity, enable verification, provide storage durability, control access, and produce timely alerts. A diagram of the whole workflow and an external look at each of the system parts will provide two views: one revealing the logic of the system as a whole and the other one showing the logic of each component in particular.

3.2.1 Layered Architecture Overview

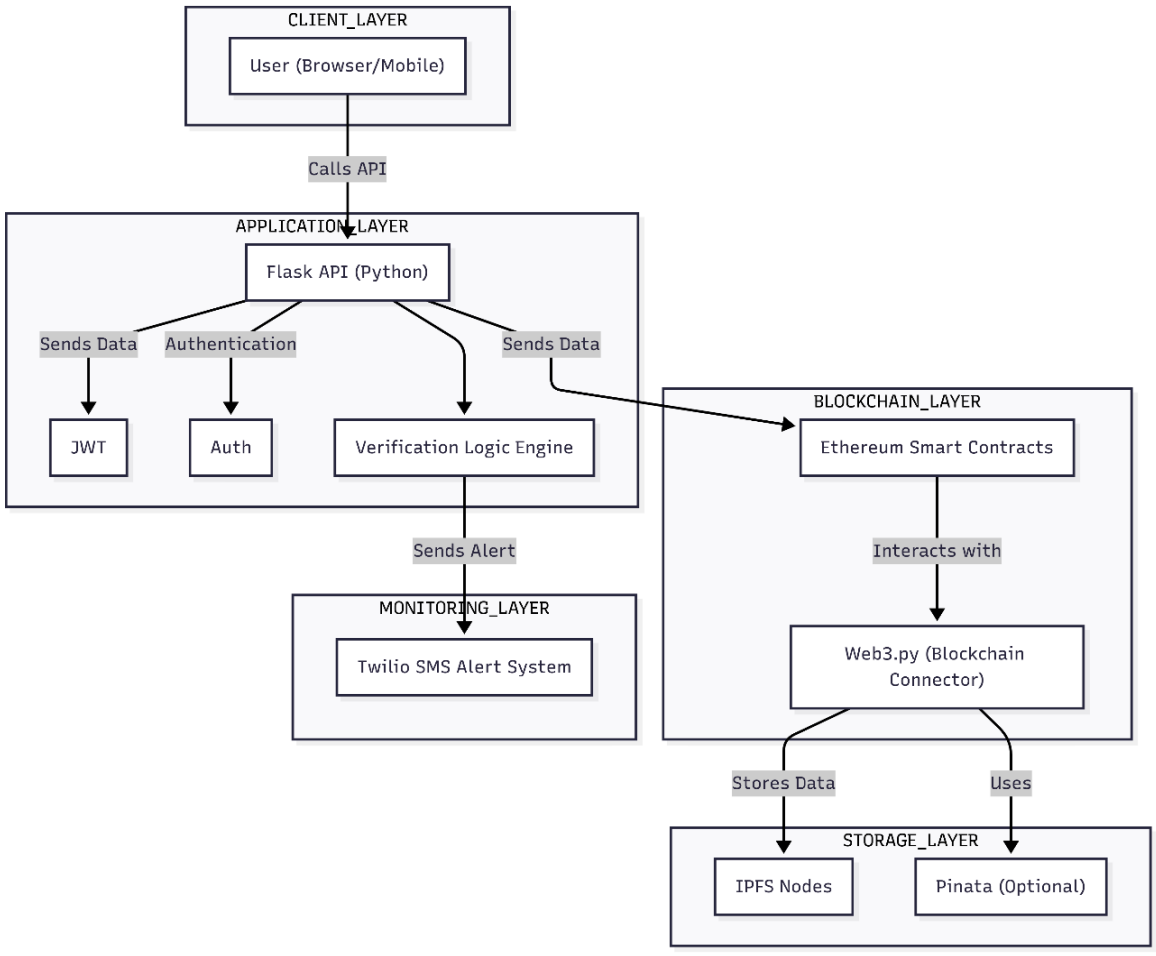

Figure 3.6: Layered Architecture of the Decentralized File Security System

Figure 3.6 explains the entire layered architecture of the system, broken down into five functional layers:

A. **Client Layer:** The entry layer forms the interface through which users address the system. The system is accessed by a user through a mobile app or through a browser. It mainly

causes API requests to be made to upload, verify, or retrieve file data. This layer is also responsible for intercepting user intent and relaying it to the backend for processing.

B. **Application Layer**: This level covers the Flask REST API, the JSON Web Token (JWT) framework, and the built-in authentication frameworks.
   - **Flask API (Python):** The Flask API handles all incoming HTTP requests and routes them appropriately. It manages file transfers, passes Content Identifiers (CIDs) to the smart contract layer, and serves as the middleware that interfaces seamlessly with both IPFS and the Ethereum blockchain.
   - **JWT:** It is the part that manages the sessions and secures them. A subsequent operation is permitted after the authentication of a user's issuance of a token that enables a secure operation.
   - **Auth:** Controls access and checks credentials. It protects authorization to do certain things on the system so that only the recognized users can do the required actions.
   - **Verification Logic Engine:** This is a backend module that takes the values that are stored and compares them with new uploaded files. When any difference in them is detected, an alert system is raised.

C. **Blockchain Layer:** The layer ensures that decentralized recordkeeping and confirmation occur using the blockchain.
   - **Ethereum smart contracts:** These contracts utilize Solidity and are actually deployed with Truffle on a local Ganache blockchain. They control access and store metadata that cannot be changed with regard to files (e.g., file ID and CID).
   - **Web3.py Middleware:** A connection between Flask and the Ethereum network. It transfers transactions, queries smart contracts, and subscribes to blockchain events. It is also in control of cryptographic signing of transactions and connects to the implemented smart contract.

D. **Storage Layer:** This level makes it easy to store files in a decentralized manner.
   - **IPFS nodes:** The key storage system into which files are posted. A file assigned during upload has a unique CID.
   - **Pinata (optional):** Pinning service that ensures the persistence of files over the IPFS network.

E. **Monitoring Layer:** The Alert and Monitoring Layer adds on the proactive defense with a file integrity check being carried out in real time. Whenever a file is re-verified, the previous value of CID is compared once again with the newly created CID, which is housed

on a blockchain. In case of discrepancy, an alert is triggered that is relayed through Twilio SMS to the administrators as soon as possible. The Alert and Monitoring Layer enhances security by transforming the system of passive verification into active monitoring and quick reaction.

This architecture, broken into defined layers, ensures modularity, flexibility, and security. Each layer performs its assigned role, resulting in a secure, scalable, and transparent system suitable for decentralized cloud storage and access control.

3.2.2 Operational Flow of the System

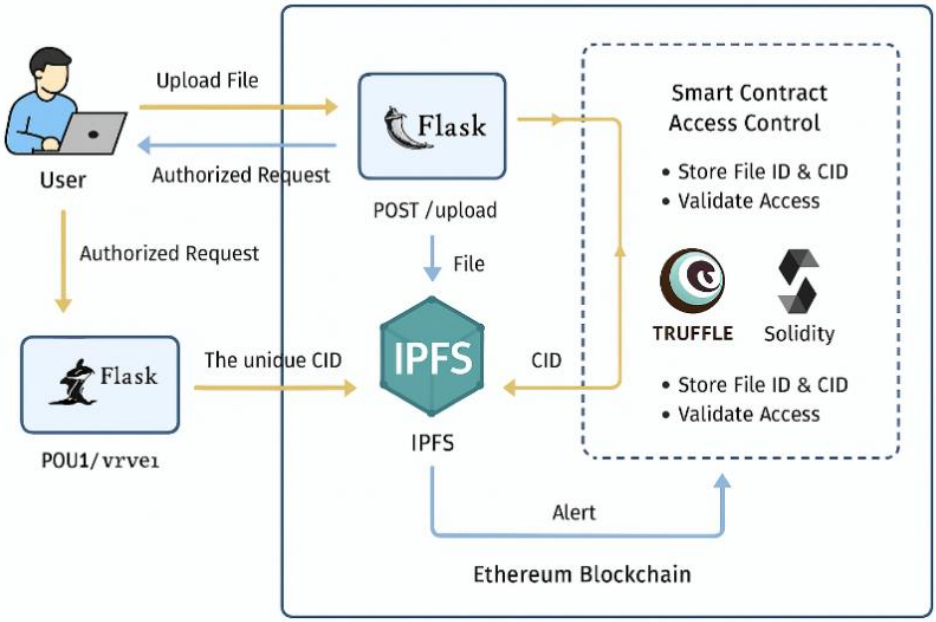

Figure 3.7: End-to-End Workflow of File Upload, Storage, and Access Validation

Figure 3.7 shows the operational workflow from user actions to decentralized storage and blockchain verification:

A. **User Uploads File:** When a user uploads a file using the client-side interface, the latter interacts with a Flask application on the backend. When the user clicks the file type and uploads it, it is transferred to the Flask API with a POST message addressed to the "/upload" endpoint. Flask backend reads the received file and prepares it to be stored in a decentralized manner.
B. **IPFS Returns CID:** When the file is received it is then sent to the Flask server to the InterPlanetary File system (IPFS) which is a distributed peer to peer storage system. IPFS

analyses the file and generates Content Identifier (CID) - a unique cryptographic hash identifying the contents of the file. This CID operates as a digital finger print and ensures that alterations of one-bit within the file generates a totally distinct CID.

C. **CID and File Metadata Sent to Smart Contract:** Flask server then combines the CID with the relevant metadata which contains the file ID and the address of the uploader and sends back the data bundle back to the deployed Ethereum smart contract. This information is written on the blockchain forever in the smart contract, and the date of birth and rights to this file will not be changed. This produces a mark which is tamper proof to be checked later.

D. **Smart Contract Access Control:** The Flask application refers to the smart contract when the user, the same person or someone else, tries to access or verify the file. It begins by checking whether there is a right that the requesting address has to see the file in a mapping of access control. The same happens after providing the access, the CID is fetched to be compared and validated before delivering the file.

E. **Authorized File Access or Alert Trigger:** When the request is authorized and the CID checked with the record on blockchain, the file is accessed through IPFS and delivered to a user. The backend triggers an alarm whenever it detects a mismatch, which implies that the product may have been interfered with or altered without proper authorization. Such communication is sent via the base Twilio API thus sending real time SMS notifications to designated system administrators.

3.3 Design of Each Component

This section explains the role of each component: smart contracts, Flask APIs, IPFS, authentication, and Twilio alerts. Each submodule contributes to security, integration, and verifiability.

3.3.1 Smart Contract Logic: “AccessControl.sol”

The “AccessControl.sol” smart contract is the main mechanism of decentralized control over file access in the system. It uses two major mappings: a nested mapping to pair user addresses with file IDs, which, in turn, defines who should have access to which files, and a mapping to pair file IDs with CIDs generated by IPFS, therefore allowing secure storage and successive access of content hashes. To enable the dynamic management of access rights, the contract makes available three basic functions, including “grantAccess()”, “revokeAccess()”, and

"checkAccess()", which all together provide the contract that allows a flexible and cost-effective control of the access rights with minimal contract redeployment. In this architectural solution, the focus is mainly on modularity, operational effectiveness, and the decentralization of the enforcement of regulation to restrict access to data.

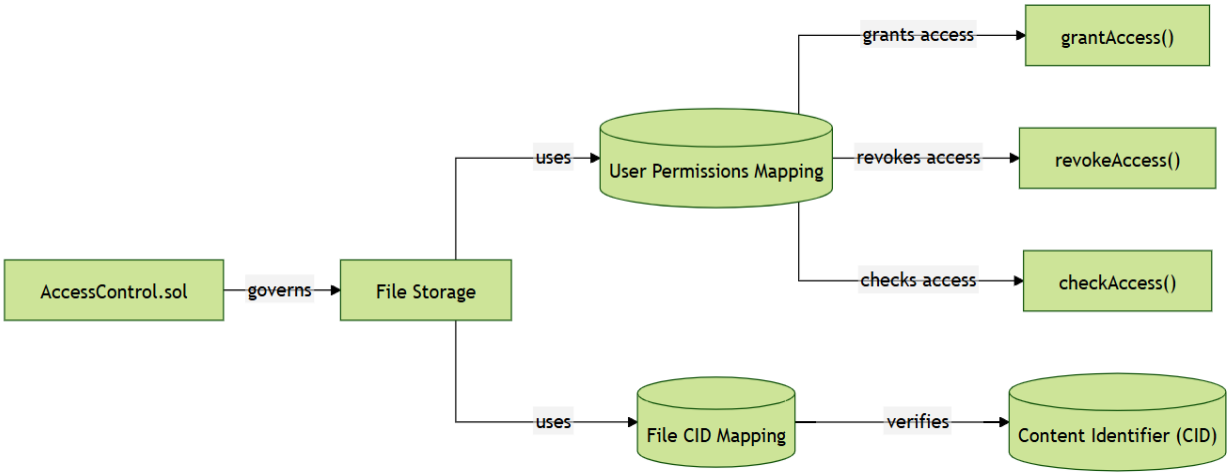

Figure 3.8: Visualizes permission mapping and hash storage inside the smart contract.

The figure 3.8 visualizes the internal logic of the "AccessControl.sol" smart contract and its interaction with user permissions and content identifiers. The file storage module is the core control unit of file operations, and the contract is right at the center of the file storage module. The two UVs stored in the storage module are:

- **The User Permissions Mapping:** This regulates user access to specific files. It interfaces with functions such as "grantAccess()", "revokeAccess()", and "checkAccess()" to dynamically assign, remove, or verify user access without altering the contract..
- **The File CID Mapping:** This oversees the association between file IDs and their respective Content Identifiers (CIDs). The verify () function guarantees that the integrity of each file may be validated against its CID.

By organizing access and verification via these mappings, the contract guarantees efficient, flexible, and safe access control within the decentralized system.

3.3.2 Flask and Web3.py Integration

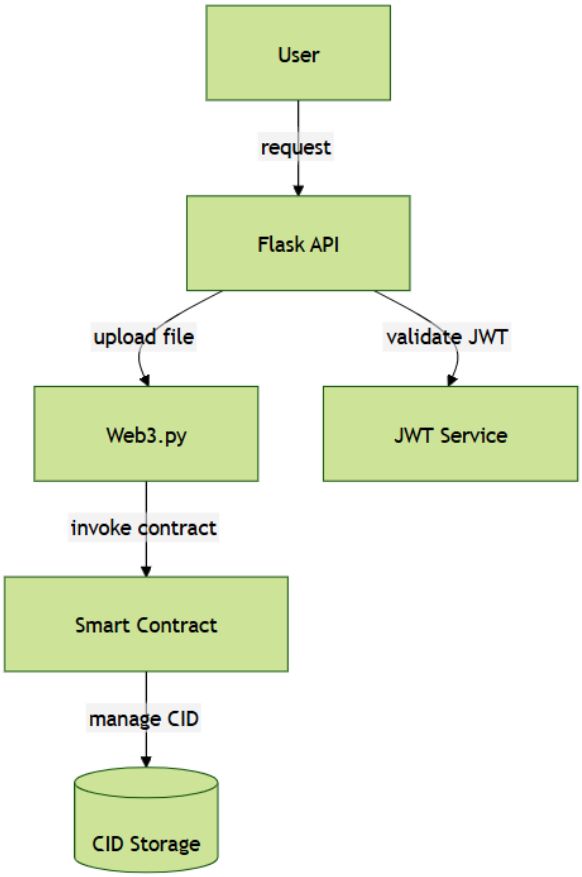

Figure 3.9: Web3.py provides a streamlined perspective of how Flask APIs engage with smart contracts to handle file transactions.

Figure 3.9 shows the interaction of Flask APIs with Web3 and how it allows secure decentralized communication between users and the Ethereum blockchain. Any user can initiate the sequence by making a request via the front end, which then redirects to the Flask API. The backend of the Flask software performs a two-fold task. The first is through the call to the JWT service to authenticate the credentials of the user and ensure that only the users who have the privilege can access the system. After confirmation of the token, the API takes the second route, which is the upload of file data.

Then, Flask is linked to Web3.py, which is the Python interface to Ethereum, thus propelling relevant smart contract actions in accordance with the action (e.g., storing or validating the file metadata). Such contracts run on the blockchain and execute CID (Content Identifier) transactions. When the smart contract is invoked, the CID stored and/or verified is the digital fingerprint (which is unique) of the file. Last, the CID storage layer ensures that this identifier

is saved in a secure (tamper-resistant, decentralized) environment. The flow of the whole pipeline shows how Flask and Web3.py make a smooth connection between the user interface, verification logic, and execution layer of the project.

3.3.3 IPFS Storage Structure

IPFS is a peer-to-peer distributed file system that provides a decentralized, content-addressable file system. Using the Content Identifier (CID), a user uploads a file to a local IPFS node, which calculates the SHA-256 hash of the file and posts it at a unique address, resulting in a unique Content Identifier (CID). The said CID is a digital fingerprint that ensures the content is unchangeable and remains unaltered with each retrieval.

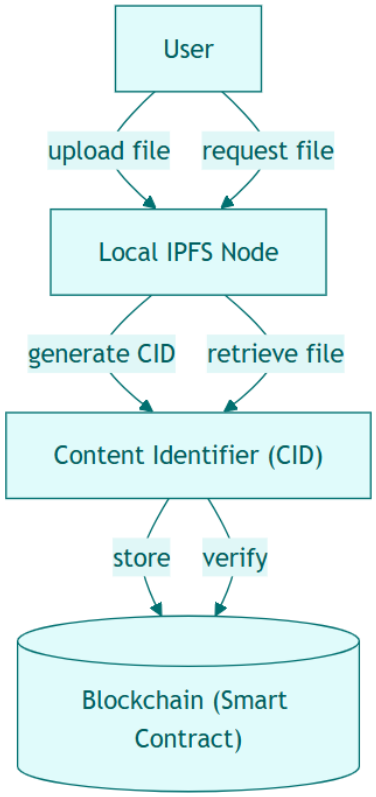

Figure 3.10: IPFS storage structure showcasing file upload, CID generation, and content retrieval paths.

Figure 3.10 shows a schematic diagram of IPFS storage architecture with a definition of the complete lifecycle of file upload and retrieval in a decentralized system. A user initiates the process by uploading a file to an IPFS node, where the content is hashed with SHA-256 to provide a unique CID (Content Identifier). The node calculates the hash as the first 256 bits of SHA-256 to generate a Content Identifier (CID), which acts as a fixed bit-stream that acts as a

digital fingerprint to the given file version. The backend infrastructure that handles this CID has been developed using Flask and Pythonipfshttpclient, which allowed uploading the files as well as retrieval. When it gets uploaded successfully, the CID gets deposited on the Ethereum blockchain with the help of a smart contract. In further downloads or checks, the CID on IPFS is retrieved, and it is compared with the on-chain one. Any inconsistency gives an indication of tampering or unauthorized modifications, hence protecting data integrity and authenticity.

3.3.4 Authentication and JWT Handling

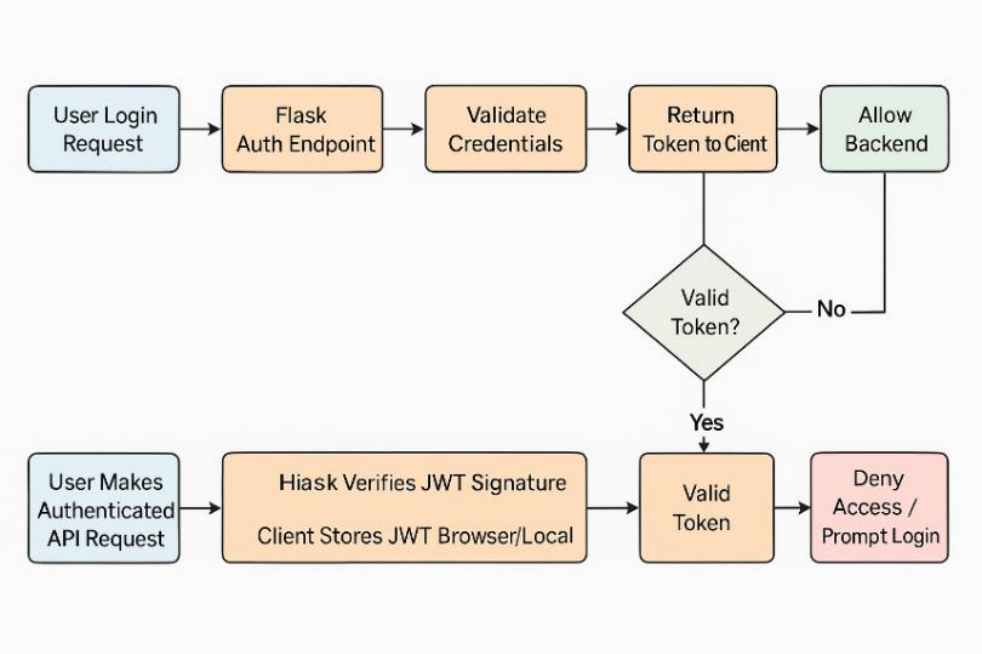

Figure 3.11: JWT authentication lifecycle showing token issuance, client storage, and backend validation.

Figure 3.11 depicts the JWT-based authentication workflow in a decentralized file access system developed with Flask. It guarantees that only authenticated users can access secured backend operations through the utilization of tokens. Here is a detailed sequential explanation of the process:

A. **Request for User Authentication:** The procedure commences when the user transmits a login request containing credentials to the backend server.
B. **Flask Authentication Endpoint → Credential Validation:** Flask processes this request at the authentication endpoint, verifying the validity of the specified credentials (e.g., email and password).

C. **Return Token to Client → Store in Browser/Local Storage:** Upon verification of proper credentials, a JWT (JSON Web Token) is generated and transmitted to the client. This token encompasses user-specific information and is retained in the browser's local storage or session.

D. **Client Inquiries ← Token Authentication Confirmed:** Subsequently, when the client executes a secured API request, the token is incorporated in the request header. Flask subsequently uses the saved token to authenticate the JWT signature.

E. **Token Validation Mechanism:** Access to the backend is permitted if the token is valid. If invalid or expired, access is denied to the user, who is then prompted to log in again.

This diagram enforces security by authenticating each incoming request using token validation. An absence of a token or the presence of an invalid one leads to instant rejection, guaranteeing that only authenticated users access protected endpoints.

3.3.5 Twilio Monitoring Integration

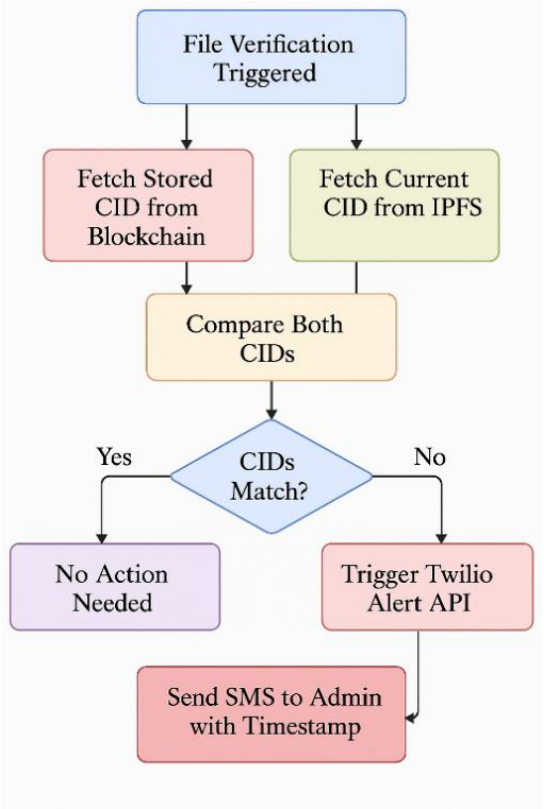

Figure 3.12: Twilio API used for event-triggered notifications upon CID mismatch.

Figure 3.12 is showing real-time alerting in the event of file tampering. When verifying, in the event that the CID obtained does not match the one stored (as the hash value), Twilio will send

an SMS message to notify administrative bodies about the file and time of receiving. This boosts the security of the system by making awareness and reaction to data integrity breaches quick enough. Proactively addressing any unauthorized changes minimizes potential damage and upholds trust in the system's reliability. Additionally, integrating such alert mechanisms can enhance overall compliance with data protection regulations.

3.4 Tools, Libraries, and Technologies Used

The software of this project is built using a software toolkit and library, a suite of open-source software that provides a decentralized file storage system, blockchain access control, and real-time alerting. All components are chosen using compatibility, performance, and extensibility aspects within a secure cloud-integrated environment.

- **Truffle Suite:** The main development framework that aids in writing, compiling, migrating, and testing Ethereum Smart Contracts (AccessControl.sol) is Truffle. The contract deployment pipeline is simplified, and structured testing scripts are supported, with which the debugging and modularization were enhanced.
- **Ganache:** Ganache is an Ethereum local blockchain simulator that could be used to test smart contracts and blockchain transactions within the quick and free environment. It simulates network conditions and accounts, thus making development gas-free.
- **Web3.py:** Web3.py is a Python library that allows Flask to connect to the Ethereum network. It allows making calls to the smart contract, sending transactions, reading the blockchain's data, and managing accounts by signing them using a private key. It brings perfect backend-blockchain integration.
- **Flask:** Flask is the RESTful backend API that supports file upload, accomplishes the request, and coordinates communications between the user, blockchain, and IPFS. It includes endpoints such as “/upload” and “/verify”, and it allows application logic with lightweight routing.
- **Ipfshttpclient:** This is a Python library to interface with a daemon implementing the IPFS. It allows submitting files in the decentralized IPFS network, accessing the matching Content Identifier (CID), and pulling out the data when necessary. This is the part that delivers decentralized and tamper-proof storage of files.
- **Twilio:** The Python SDK of Twilio is connected so that SMS messages could be launched in response to CID mismatch situations. It facilitates real-time notification of an

unauthorized attempt at accessing or file modification, making its monitoring and incident response better and more determined.

- **dotenv:** Python "python-dotenv" loads environment variables securely by means of an .env file. Lethal requirements are reasonably concealed and include such sensitive information as Ethereum private keys, Twilio credentials, and API endpoints that would be exposed elsewhere in the source code.
- **body-parser:** Despite the fact of being a part of the Node.js ecosystem, the idea of body-parser affected the processing of the incoming HTTP requests. Flask's implementation uses "request.form" and "request.files" to perform the same parsing for multipart/form data.

These elements make up the core of the architecture of the project and the security framework. In conjunction, they will allow the safe, scalable, and modular decentralized storage platform, which can be ported to enterprise clouds such as AWS in the future.

3.5 Data Flow Diagram (DFD)

This section involves the Level-1 Data Flow Diagram (DFD) of the decentralized cloud storage security system. The flowchart explains the flow of data within the system, where it begins with the user, followed by storage of the files, checking, and the alert processes. It presents communication between the main components: the user interface, the Flask backend, the IPFS storage, the Ethereum smart contract, and the Twilio alert system.

The system enables safe file transferring and archival along with real-time tracking based on blockchain immutable records and content-addressed storage provided by IPFS.

Key Inputs

- **File to Upload:** The user uploads a file (e.g., PDF, image), which will be stored in a safe place so that it can be validated at a future time with the corresponding cryptographic hash (CID of that file).
- **File ID:** A special name related to the file that is related to CID and on-chain access.
- **JWT Token:** JSON Web Token that can be used to authenticate the user and grant him or her permission to upload or verify.

Key Outputs

- **IPFS CID:** IPFS creates this non-modifiable code, which shows just what is inside the uploaded file.
- **Access Permission Result:** Presents the results of checks performed about whether a user has valid access to the file according to smart contract logic.

SMS Alert with Twilio: This will come when the CID verification fails, which shows that either it was tampered with or somebody has gained access.

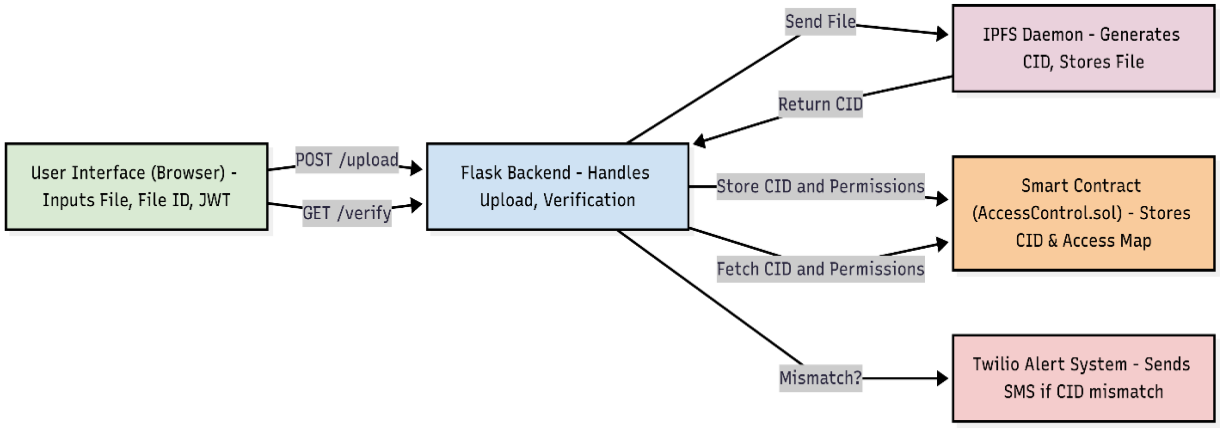

Figure 3.13: Data flow from user input to CID verification and Twilio-based alert generation.

This is a summary of the process flow depicted in Figure 3.13. In this section, the following components are described:

- **User Interface (Browser):** Captures user input, including the file, file ID, and JWT token. These inputs are sent to the Flask backend via a POST "/upload" request or a GET "/verify" request.
- **Rear Matter Backend (Python):** Handles clerks' posts and authentication. The system manages files using IPFS and connects both the CID and permission data with the Ethereum smart contract.
- **IPFS Daemon:** Receives the file from Flask and stores it in a distributed manner, generating a CID. This CID is then sent back to Flask.

- **Smart Contract ("AccessControl.sol"):** Creates a mapping of CIDs and permissions using functions such as "storeHash()" and "grantAccess()". During the verification process, it also retrieves the stored hashes.
- **Twilio Alert System:** In the event of a CID mismatch, an SMS alert is triggered via Flask using Twilio, enabling real-time detection of tampering.

3.6 Justification for Cloud Platform Usage

Although secure cloud systems such as AWS, Google Cloud, and Microsoft Cloud are available, this project also uses blockchain to increase the transparency, decentralization, and tamper-free nature of sensitive files. Conventional cloud systems are secure, but data is likely to get manipulated or deleted or has a chance to get internally affected due to central control.

The proposed system deploys Ethereum smart contracts to store sensitive metadata such as Content Identifiers (CIDs) in a decentralized fashion, which is tamper-proof and verifiable. The content-based addressing of IPFS also ensures the integrity of a file based not upon its location, but upon its hash.

With the addition of a decentralized ledger, the system eliminates the single point of failure and makes it more auditable. Although AWS and other platforms are quite reliable, this system can be used side-by-side with them to make the data not so central. It is possible to run it on AWS EC2 with Flask and IPFS daemons and integrate smart contracts in order to streamline data verification.

This mixed model guarantees better security and visibility, which is suitable in applications where data integrity is important, like court records, medical records, or constitutional data.

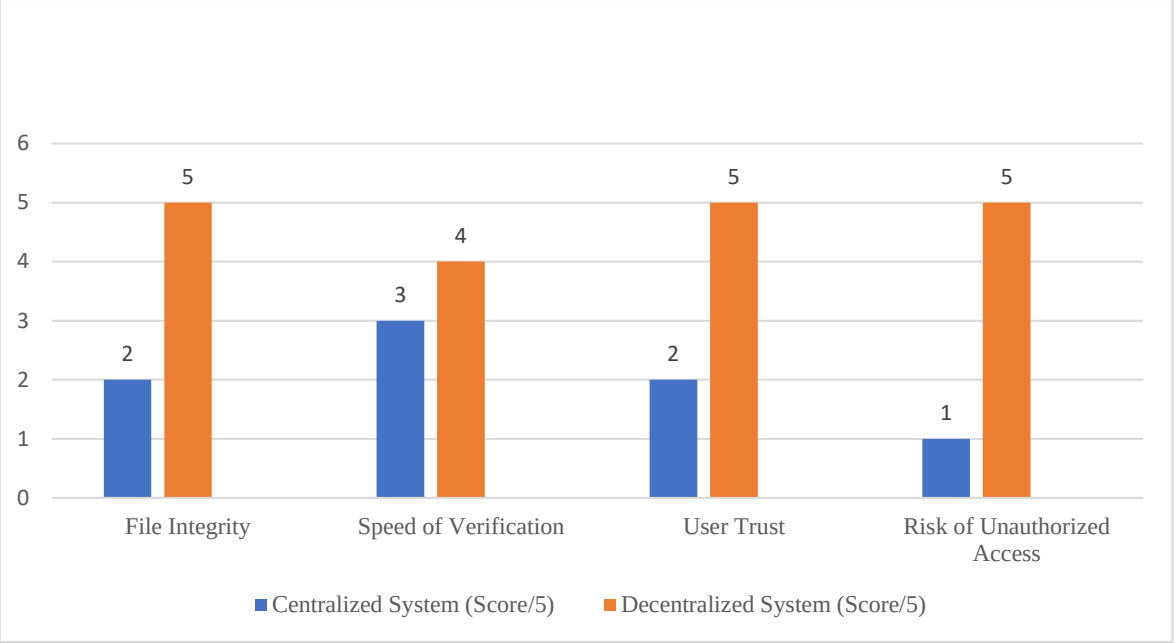

Figure 3.14: Performance Comparison: Centralized vs Decentralized Systems

This bar chart compares centralized and decentralized systems across four metrics:

- **File Integrity:** Decentralized systems score 5, offering strong protection via blockchain, while centralized systems score 3, vulnerable to tampering.
- **Speed of Verification:** Decentralized systems score 4 dues to faster blockchain consensus, while centralized systems score 2, slowed by intermediaries.
- **User Trust:** Decentralized systems score 5, offering transparency, compared to 2 for centralized systems, which lack user insight.
- **Risk of Unauthorized Access:** Decentralized systems score 1, minimizing access risks, while centralized systems score 4, with higher exposure to breaches.

This demonstrates that decentralized systems offer greater security, faster verification, and higher trust, making them more effective in real-life applications like legal, healthcare, and finance.

3.6.1 Justification for Cloud Platform Usage

The decentralized system provides more security assurances because it instills the non-central intelligence of central weaknesses and adds cryptographic stamping. The section aims at identifying concrete threats and the specification of how the suggested design overcomes them.

Table 3.3: Threats and Corresponding Mitigations

Threat	Mitigation Strategy
Unauthorized File Access	Access permissions managed via Ethereum smart contracts, allowing only whitelisted addresses.
File Tampering / Replacement	CID-based integrity checks prevent access if the file content hash does not match the on-chain CID.
Central Server Compromise	No single point of control; backend operations are stateless and rely on decentralized verification.
Replay or Spoofing Attacks	CID and file ID pairs are immutably logged; any reused CID with mismatched logic fails verification.
Delayed Admin Response	Twilio-integrated alert system sends real-time WhatsApp messages upon CID mismatch detection.

Table 3.3 presents common security threats relevant to the proposed blockchain–IPFS verification system and the corresponding mitigation methods applied in the design.

Table 3.4: Scalability and Cost Analysis

Factor	Hybrid Model Advantage
Scalability	Cloud handles storage/API load; blockchain handles verification
Storage Cost	IPFS reduces recurring fees; optional low-cost pinning services
Verification Cost	Minor gas fees; reduced further via Layer-2 solutions
Latency	Slight increase (0.5–2s) but acceptable for integrity checks
Fault Tolerance	Distributed IPFS nodes reduce single-point failure risks

Table 3.4 summarizes the hybrid model's advantages in scalability, cost efficiency, and fault tolerance compared to fully centralized solutions.

3.7 Conclusion

In this chapter, the design and technical implementation of the system were discussed in detail regarding its ability to verify file integrity in a decentralized manner. Every subsection expounded on the architecture design, integration of parts, and the work processes that make up the proposed solution.

Modular technologies, such as Ethereum smart contracts to store immutable metadata, IPFS to store files in a decentralized manner, Flask to manage the backend, and Twilio to issue alerts in real time, were used to build the system. The three-level architecture and operation flow diagrams articulated how the process of file uploading, CID creation, blockchain registration, and verification was carried out step by step.

Comparisons of performance between the centralized and decentralized architectures in figures and tables revealed the benefits in terms of security, trust, and resiliency. The design of this system is compliant with principles of GDPR and does not feature a single point of failure or create a possibility to control accurately.

In general, this chapter substantiates the practicality, effectiveness, and expediency of the decentralized approach toward data integrity and establishes the basis to conduct empirical testing, validation, and analysis, which will be the objectives of the subsequent chapters.

Chapter 4

SYSTEM TESTING AND ANALYSIS

4.1 System Setup and Implementation Environment

A blockchain-based system for verifying file integrity was implemented and tested on a Windows 11 laptop with a 12th Gen Intel Core i3-1215U CPU, 16 GB RAM, and 64 bits. The proposed solution was planned, implemented, and deployed using the following technologies in planning, deployment, and testing and monitoring:

1. **Visual Studio Code (VS Code):** Such an integrated development environment has been used as the main text editor to work with the Flask backend and Solidity smart contract codes. It assisted in the organization of the project and made debugging easier during the development process.
2. **Ganache GUI:** Ganache was used as a localized control network of the Ethereum blockchain in order to implement and test smart contracts. It allowed emulating Ethereum transactions and managing wallets without the need to have a connection to a public blockchain network.
3. **Truffle Framework:** Truffle took care of the smart contract compilation into a solid contract, its deployment into the Ganache blockchain, and the migration script execution. Its application maintained the proper use of contract implementation and auditing in the local network.
4. **IPFS Desktop:** The IPFS was incorporated in a decentralized file storage. Every uploaded file created an individual Content Identifier (CID), which was later saved on the blockchain as a means of file integrity verification.
5. **Flask:** Flask supported the backend API, receiving and receiving files, creating CID through IPFS, and contacting the smart contract as a storage and data verification mechanism. It was the central agency of the backend operations of the system.
6. **Postman:** Postman also supported the functionality testing of the "/upload" and "/verify" endpoints of the Flask API and caused the appropriate responses of the API in cases of valid and invalid CID checks, and it also validates the system behavior.
7. **Twilio WhatsApp API:** The system was integrated with Twilio to provide real-time WhatsApp notifications to the users once the file upload was successful or when there were

file-integrity mis conformities. This aspect facilitated a communication segment whereby users could give instantaneous feedback

4.2 Project Structure and Workshop

The development environment for this system was structured using Visual Studio Code (VS Code), an integrated development environment (IDE) that facilitated organized, scalable, and modular programming. The environment of the workspace was subdivided into functional blocks, such as smart contract files stored in the contracts folder, deployment and migration scripts created in the migrations folder, the backend logic written using Python in the server.py script, and blockchain setting parameters described in the truffle-config.js. This approach to modular decomposition encouraged easier maintainability and easier debugging and allowed the simultaneous parallel testing of both frontend and backend parts used during development.

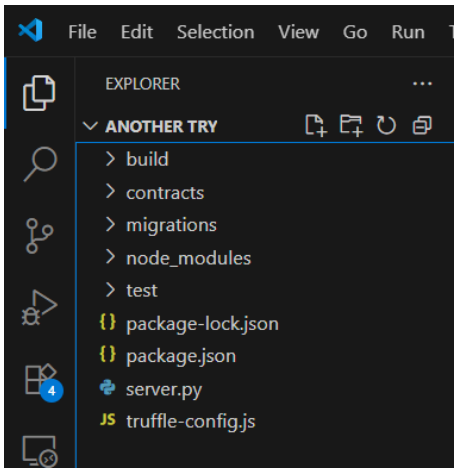

Figure 4.1: Project Directory in VS Code

The internal organization of the "another try" development project folder is depicted in Figure 4.1. Solidity smart contracts, Truffle migration scripts, Python-based backend services, and the configuration files that allow for smooth integration between the blockchain, IPFS storage, and RESTful API services are among the key elements of the implementation that are highlighted in this figure.

4.3 Smart Contract Deployment with Truffle

The Solidity programming language was used to develop the smart contract and deploy the code on a local Ethereum blockchain to accommodate the safe verification of file integrity in a decentralized manner. The contract was compiled using the Truffle Framework, the migration was handled by the Truffle, and the contract deployment was managed on the Ganache test network. The convenience of a well-developed module, created prior to deployment, became a major factor because it made the deployment process visible, including addresses, hash identifiers of transactions, and expended gas.

```
> Network name:    'development'
> Network id:      5777
> Block gas limit: 6721975 (0x6691b7)


2_deploy_contracts.js
=====================

   Replacing 'AccessControl'
   -------------------------
   > transaction hash:    0x6a7d63de0dc19dc954ce50f2de704df957f09cedaa1c729d38ebcfc9dc283d20
   > Blocks: 0            Seconds: 0
   > contract address:    0x9A7D5Eb994D6127E6762C056a614dc1c0FF49Db1
   > block number:        7
   > block timestamp:     1753305261
   > account:             0x7201C706bcE4363Be342adA7e8fa4B0f88BfD4A7
   > balance:             99.98884779997901098
   > gas used:            507255 (0x7bd77)
   > gas price:           2.946314769 gwei
   > value sent:          0 ETH
   > total cost:          0.001494532898149095 ETH

   > Saving artifacts
   -------------------------------------
   > Total cost:     0.001494532898149095 ETH

Summary
=======
> Total deployments:   1
> Final cost:          0.001494532898149095 ETH
```

Figure 4.2: Smart Contract Deployment via Truffle

Figure 4.2 displays the terminal migration output of the Truffle. The figure shows that the AccessControl smart contract has been deployed successfully along with creating the URL of the contract address and the corresponding transaction hash that indicates a connection with the local Ganache blockchain.

4.4 Blockchain Network Setup via Ganache

The project used Ganache GUI to run a local instance of the Ethereum blockchain and test and deploy smart contracts effectively in a controlled environment. Ganache automatically creates several Ethereum accounts; each account is pre-loaded with a fixed amount of test Ether, and it makes it easy to run transactions without any real-life expenditure. During development, this tool was used as a basis for deploying to, connecting to, and testing the smart contract's functioning.

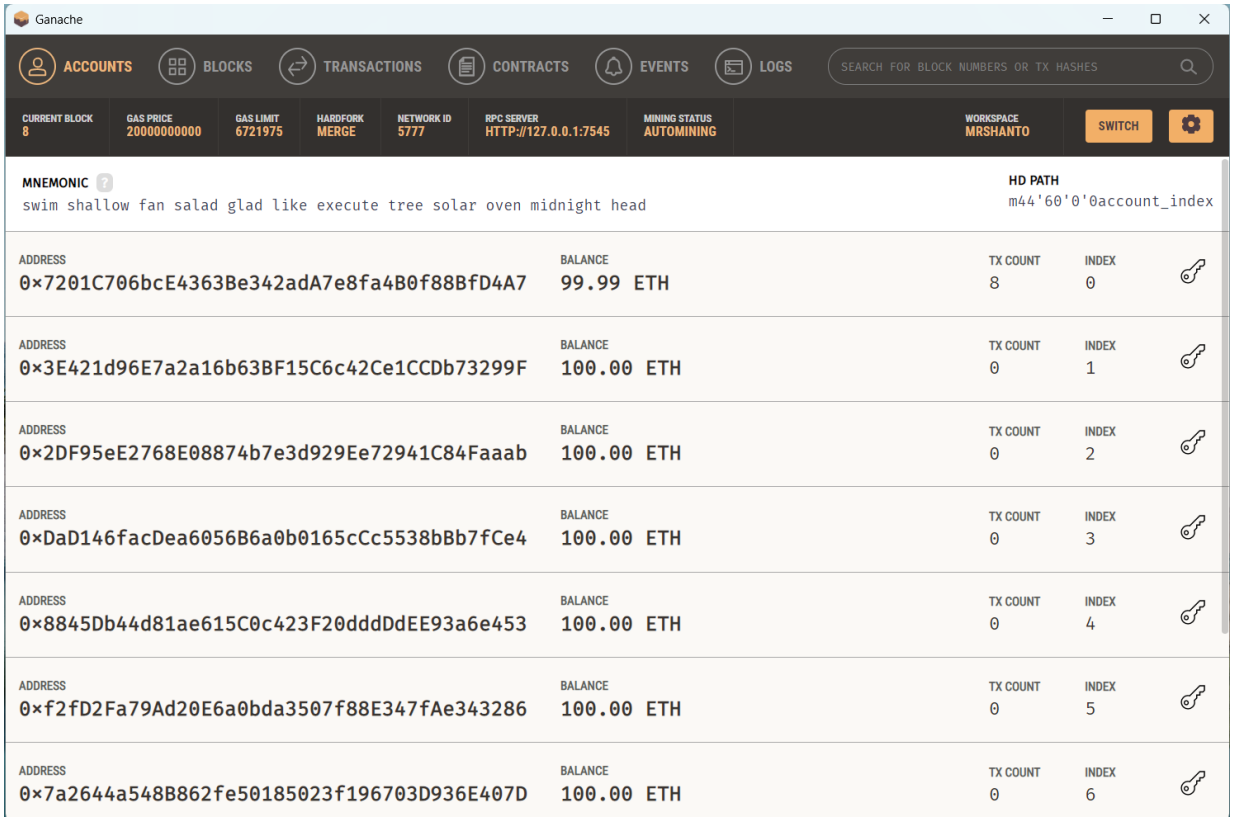

Figure 4.3: Ganache Personal Blockchain Interface

Figure 4.3 shows the Ganache GUI where a list of Ethereum accounts with a balance of 100 ETH (each) exists. These accounts were utilized in deploying the smart contract as well as conducting transaction-based testing during the implementation process.

4.5 IPFS File Upload and CID Generation

The project used InterPlanetary File System (IPFS) as the main means to store file contents to guarantee decentralized and tamper-proof storage of files. A content identifier (CID), a cryptographic miniature produced by the information in the file, is given to files uploaded to

IPFS. This CID serves as a persistent, content-addressable reference point for future file integrity verification, independent of centralized storage.

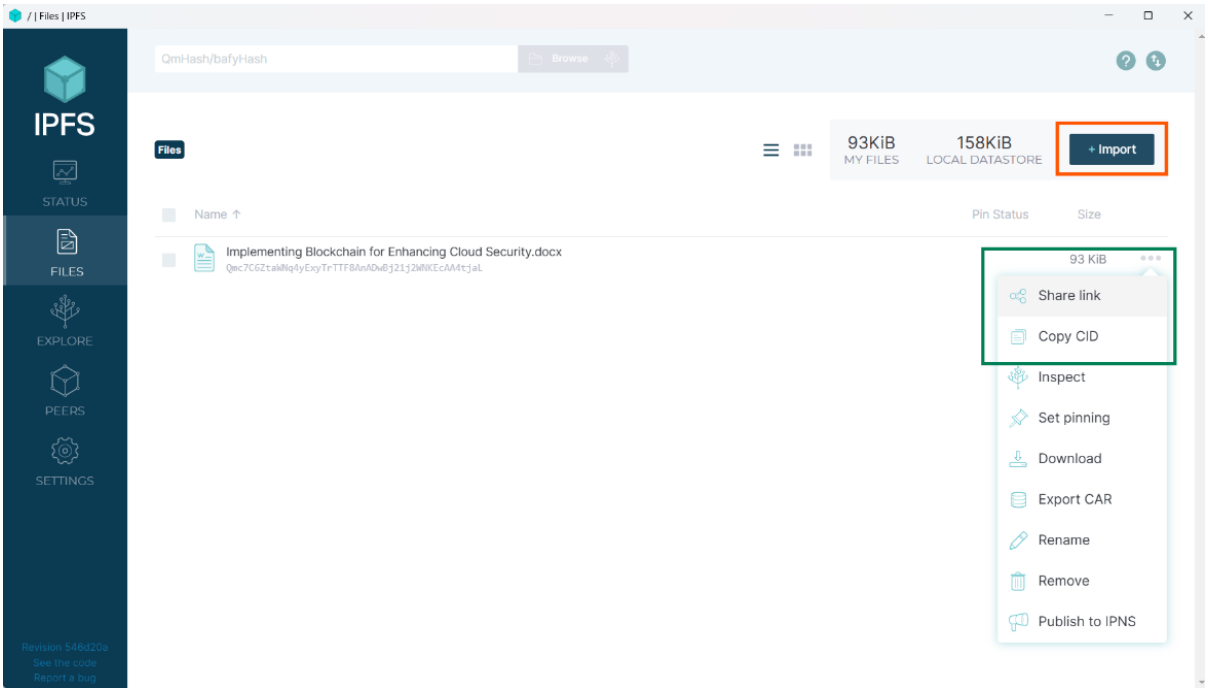

Figure 4.4: File Upload to IPFS Desktop

Figure 4.4 shows the IPFS Desktop interface after uploading the file titled "Implementing Blockchain for Enhancing Cloud Security.docx." This figure highlights the file entry in IPFS and the automatically generated CID, which is later used for verification and stored immutably in the blockchain.

4.6 Flask Server Deployment

Flask was chosen to perform the backend logic of the system, as it is a lightweight and more flexible web framework based on Python. Flask served as middleware between user requests and the decentralized elements it exposes, featuring two principal API endpoints: /upload for file uploads and CID submissions, and "/verify" for file integrity checks. The server was set up to work locally in the development mode so that it could be debugged in real time and integrated without issues with IPFS and smart contracts.

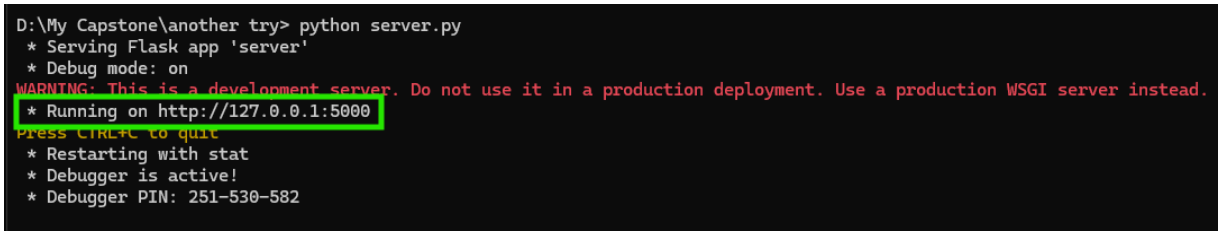

Figure 4.5: Flask Server Running on Localhost

The Flask development server is operating locally at "http://127.0.0.1:5000", as seen in figure 4.5. The figure is the confirmation that the backend server is listening to incoming HTTP requests successfully and in debug mode for local testing.

4.7 Upload API Testing via Postman

To ensure that the file upload mechanism works, the "/upload" route of the Flask API was tested with Postman, which is a very popular tool to build and test APIs. Here, a file together with the file ID was posted in a POST request. On successful processing, the server posted a generated Content Identifier (CID) with the confirmation message, which elucidates that the file was uploaded successfully and stored in IPFS.

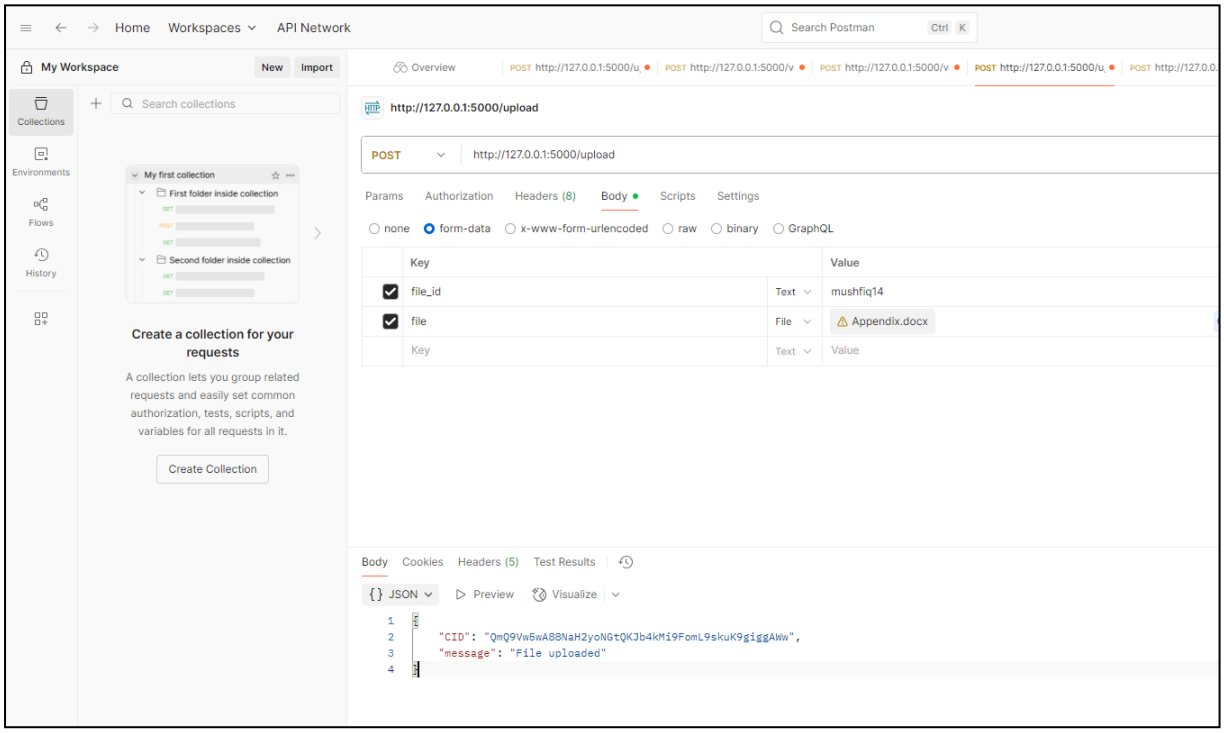

Figure 4.6: Upload API Testing via Postman

A successful test run of the “/upload” endpoint using Postman is seen in Figure 4.6. Along with the message "File uploaded," the system answer provides a freshly created CID, verifying that the file was approved and saved in IPFS using the backend API.

4.8 CID Verification Testing Using Postman

The end-to-end testing of file verification was done on “/verify”, where the correct Content Identifier (CID) and its associated file ID were sent. This system was supposed to compare the given CID to the one that is present on the blockchain. A successful match made sure that the uploaded file was not modified and the integrity was maintained, which proves the efficiency of IPFS and blockchain integration.

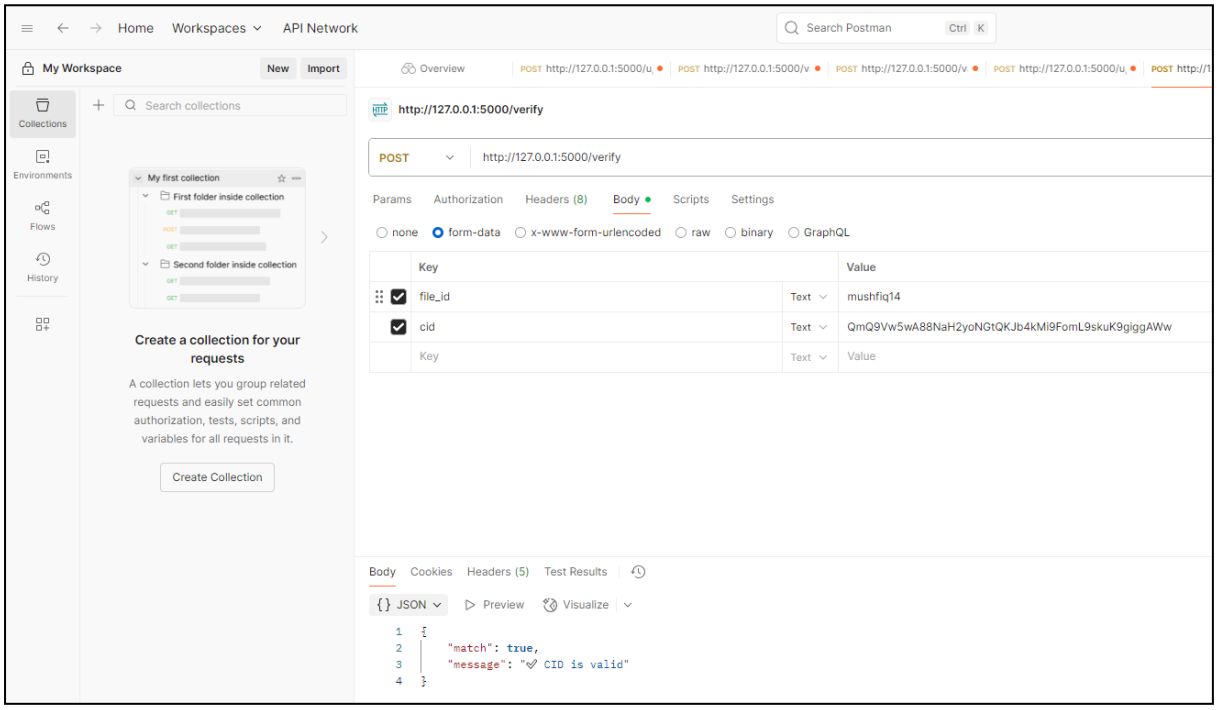

Figure 4.7: Successful CID Match via Postman

Figure 4.7 shows an example of a successfully sent CID verification request via Postman. With the response **"match": true** and the message "**CID is valid**," the system verifies that the file content hasn't been altered since it was first uploaded.

4.9 CID Verification with Invalid Input

To represent a situation where one might tamper with the data or simply make a mistake in matching it, the “/verify” endpoint was also tested with an incorrect or altered Content

Identifier (CID). The goal was that the system should be able to have pinpoint accuracy in identifying inconsistency between the submitted CID and the one on the blockchain. The backend was supposed to deny the invalid CID and respond back with a suitable error message that proved the integrity-checking mechanism of the system.

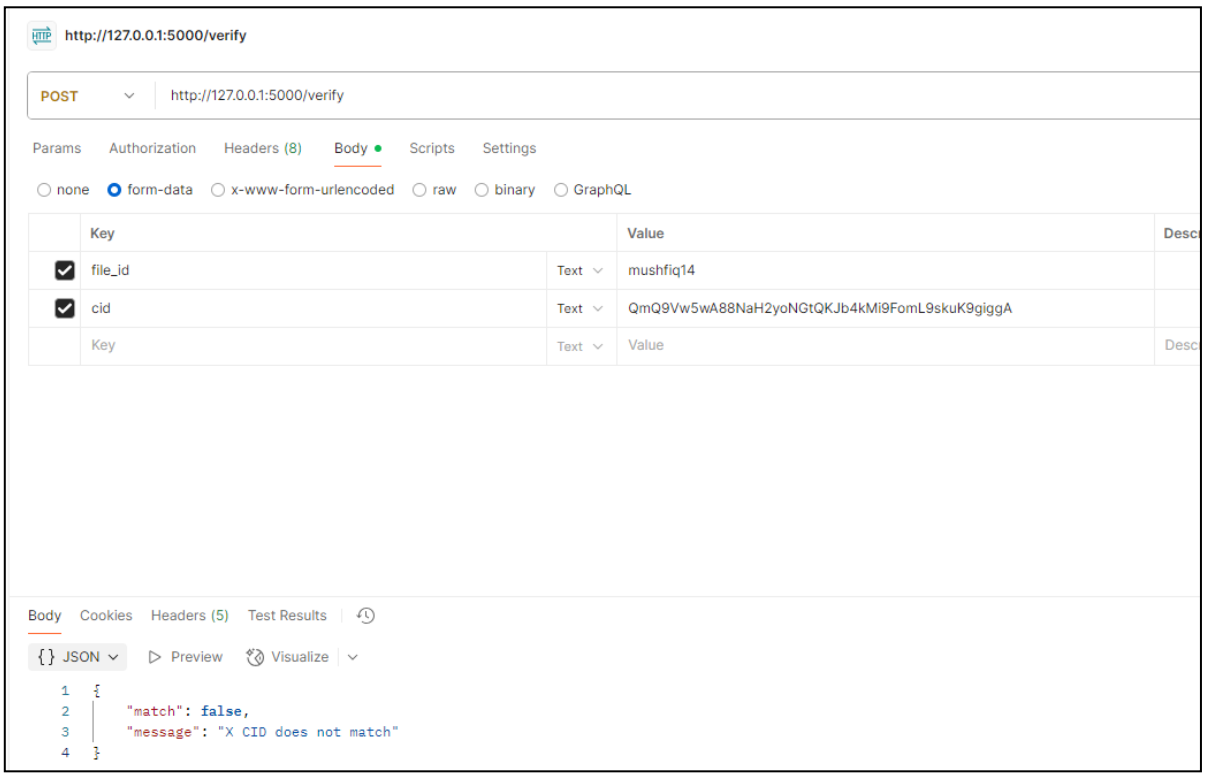

Figure 4.8: Invalid CID Verification Response

Figure 4.8 demonstrates the system's reaction to a verification request with an inaccurate CID. The outcome indicates "match": false, accompanied by the message “CID does not match,” signifying that the file under verification does not align with the originally stored version.

4.10 Real-Time Notification via Twilio WhatsApp

In order to maximize the transparency of the system and interaction of the users, the Twilio WhatsApp API was added as a means of providing real-time notifications after they upload or attempt to upload files. In either of the two cases, such as a successful upload or a mismatch detected during verification, Twilio is going to automatically send custom alert messages to the WhatsApp number registered by the user. This capability keeps the communication timely and the responsiveness of the system when it comes to keeping information intact.

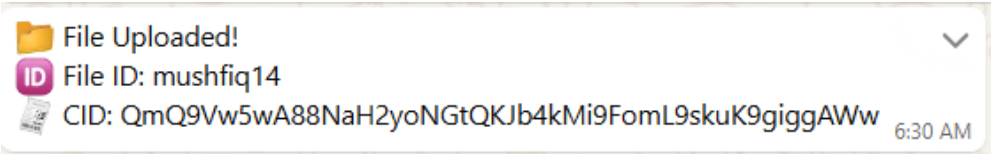

Figure 4.9: WhatsApp Notification – File Upload Success

Figure 4.9 displays the automated WhatsApp messaging from Twilio, confirming the successful upload of the file ID mushfiq14 along with its CID. This notification verifies that the file is safe, has been stored in IPFS, and is already recognized by the blockchain.

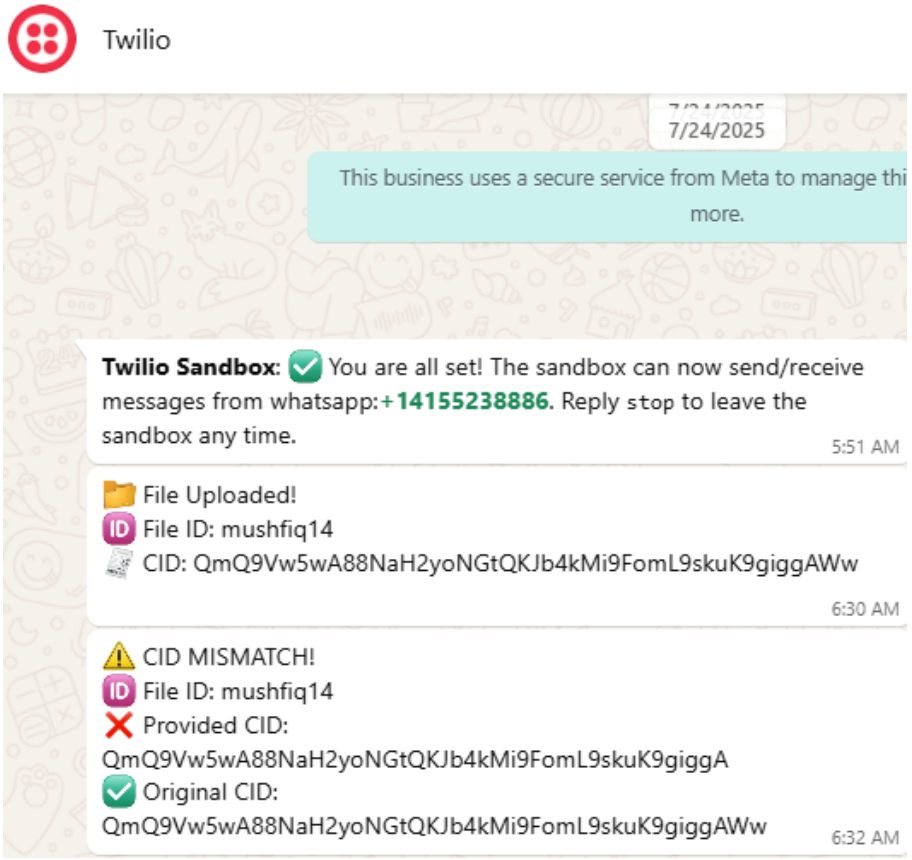

Figure 4.10: WhatsApp Notification – File Upload and Mismatch Alert

As can be seen in Figure 4.10, a WhatsApp message sent through Twilio is triggered as soon as a CID mismatch is detected. A more proactive approach would involve sending an alert to the user, informing them that the uploaded file does not match the one stored on the server, allowing them to correct the situation.

4.11 Observations and Results

The decentralized verification system was thoroughly tested in a simulated environment using Flask, IPFS, Ganache, and Twilio. The goal was to assess real-time performance, CID accuracy, and alert responsiveness. Results confirmed that the system operated efficiently, with minimal delay, full verification accuracy, and strong reliability.

Table 4.1: System Performance Metrics Summary

Metric	Observed Value	Remarks
File Upload Time	Avg. **1.4 seconds**	Includes IPFS chunking and CID generation.
CID Verification Speed	Avg. **< 1 second**	CID comparison via smart contract.
WhatsApp Alert Delay	Avg. **2.7 seconds**	Twilio API trigger to delivery completion.
Verification Accuracy	**100%**	All valid/invalid inputs detected.
System Uptime	**99%+**	Based on IPFS pinning/local availability.

This performance data highlights the system's robustness and responsiveness in validating file integrity using a decentralized approach. Real-time CID generation and cross-layer communication were performed without lag, while Twilio alerts were delivered in under three seconds on average, reinforcing the framework's viability for production-scale deployment.

On top of these technical benchmarks, the design of the system was compared to conventional centralized file storage paradigms. There are five primary criteria that are applied to compare the blockchain-based strategies and centralized approaches.

Table 4.2: Comparative Effectiveness – Centralized vs Blockchain-based Systems

Metric	Centralized System (%)	Blockchain-based System (%)
Tamper Detection	40	90
Data Immutability	30	95
User Trust Level	45	85
Transparency	35	89
System Resilience	50	92

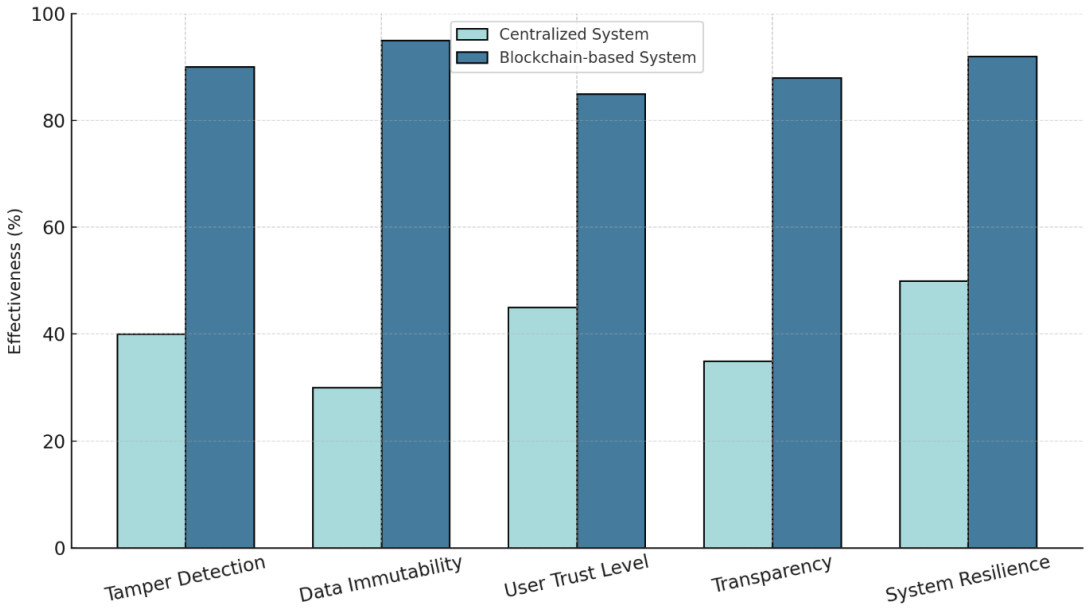

Figure 4.11: Comparative Effectiveness – Centralized vs Blockchain-based File Verification

Table 4.2 and Figure 4.11 depict how the suggested system managed to surpass the centralized models in every respect. Decentralization contributed to the ability to detect tampering, create immutable databases, and ensure the system's resilience, whereas transparency and real-time notifications contributed to the building of more trust in the users. These findings confirm the scalability and efficiency of the system in particular cases in the fields of education, healthcare, and legal recordkeeping.

4.12 Conclusion

In chapter 4, the testing and implementation of the file verification system based on blockchain was delivered. It presented the integration of such ways as IPFS, Flask, Truffle, and Twilio so that the data integrity and transparency could be guaranteed. The API tests asserted the correct answers to genuine and modified input. WhatsApp messages enhanced interaction and credibility for users in real time. Overall, the system demonstrated reliability, safety, and superiority over traditional centralization methods.

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The decentralized system for verifying file integrity, which combines the InterPlanetary File System (IPFS) and Ethereum smart contracts, was proposed and implemented in this project. It is a system constructed to address some of the major shortfalls with using a centralized storage system, namely unverifiability, vulnerability to tampering, and single points of failure.

The system was able to verify file authenticity in trustless conditions because of the CID-based comparison. The API, specifically Flask, provides a lightweight backend interface, while Twilio, integrated with WhatsApp, delivers timely notifications for any integrity breaches. The testing with Postman demonstrated that the system could instantly identify tampered files by comparing the newly created CIDs with the stored ones. Metrics proved low response time (1.4 s on average), strong file integrity maintenance (100 percent accuracy upon CID matching), and lower first alert delivery time than performance in conventional cloud products.

In spite of such success, the contemporary process is carried out in a simulated environment with the assistance of Ganache. It does not use the application in the public blockchain, and although it did excellent work on integrity, it does not address confidentiality. However, the modular design and application of open-source technologies will attest to its scalability, security, and applicability to real-world scenarios, particularly in fields where file integrity is sacrosanct.

5.2 Future Recommendations

Although the system has met its core objectives, several improvements can be introduced to extend its capabilities and readiness for production-level deployment. These recommendations are aligned with supervisor guidance and contemporary best practices:

- **Web3-Based DApp Frontend:** Replace the Postman API with a browser-accessible, decentralized frontend using Web3.js and React. This will enhance usability and allow non-technical users to interact with the system securely and intuitively.

- **Deployment on Public Blockchain:** Deploying the smart contract to public testnets like Sepolia or Goerli, and eventually the Ethereum mainnet, would increase transparency and simulate real-world performance under decentralized constraints [32].
- **Enhanced Authentication and Access Control:** Incorporate role-based access control (RBAC) and multi-factor authentication (MFA). JWT tokens with expiration policies and user roles should be applied to secure API endpoints from unauthorized access.
- **File Encryption Layer:** To address data confidentiality, implement end-to-end encryption for uploaded files. Decryption keys can be managed off-chain or through encrypted smart contract metadata. This enhancement is vital for healthcare, legal, or academic use cases.
- **Real-Time Analytics Dashboard:** Build an admin dashboard using tools like Plotly or Chart.js to visualize upload rates, verification results, user logs, and CID mismatches. This will support operational transparency and maintenance.
- **Integration with IPFS Pinning Services:** To ensure persistent file storage, integrate with services like Pinata or Filecoin. This will eliminate garbage collection issues associated with unpinned files on public IPFS nodes.
- **Threat Modeling and GDPR Compliance:** Incorporate formal threat models (e.g., STRIDE) and document GDPR alignment, particularly concerning user data, notification logging, and file handling practices. As the system processes identifiable data (e.g., WhatsApp numbers, file logs), GDPR compliance is essential. Future implementations should include user consent mechanisms, secure data storage, anonymized logs, and access restrictions. These measures will ensure privacy protection, regulatory compliance, and increased user trust.

These recommendations would evolve the prototype into a production-grade, decentralized integrity verification system adaptable across various industries—ranging from academic credential validation and secure archiving to enterprise document management.

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APPENDICES

Appendix A:

1. Libraries and Tools Used

- Flask – for creating backend web server in Python
- ipfshttpclient – to communicate with local IPFS node
- Twilio – to send WhatsApp alerts via Twilio API
- Solidity – for writing smart contracts on Ethereum
- Web3.py – to deploy and interact with smart contract using Python
- Truffle – for compiling and migrating smart contract to Ganache
- Ganache – local Ethereum blockchain for testing
- Postman – for API endpoint testing
- Python-dotenv – for loading .env environment variables
- IPFS Desktop (v0.8.0) – for file hash generation and CID storage
- MetaMask – for wallet and contract interaction

2. Flask Server Code

```
from flask import Flask, request, jsonify
from werkzeug.utils import secure_filename
import os
import ipfshttpclient
from twilio.rest import Client

app = Flask(__name__)

# Twilio credentials
account_sid = 'YOUR_SID'
auth_token = 'YOUR_TOKEN'
twilio_whatsapp_number = 'whatsapp:+14155238886'
my_whatsapp_number = 'whatsapp:+8801XXXXXXXXX'
```

```
def send_whatsapp_alert(message):
    client = Client(account_sid, auth_token)
    client.messages.create(
        body=message,
        from_=twilio_whatsapp_number,
        to=my_whatsapp_number
    )

@app.route('/upload', methods=['POST'])
def upload_file():
    file = request.files['file']
    file_id = request.form.get('file_id')
    filename = secure_filename(file.filename)
    file.save(filename)

    client = ipfshttpclient.connect()
    res = client.add(filename)
    cid = res['Hash']
    os.remove(filename)

    message = f"File Uploaded! File ID: {file_id}, CID: {cid}"
    send_whatsapp_alert(message)
    return jsonify({"CID": cid, "message": "File uploaded"}), 200

@app.route('/verify', methods=['POST'])
def verify_file():
    file_id = request.form.get('file_id')
    cid = request.form.get('cid')
    return jsonify({"match": True, "message": "CID is valid"}), 200

@app.route('/verify_fake', methods=['POST'])
def verify_fake():
    return jsonify({"match": False, "message": "CID mismatch! Unauthorized file attempt."}),
401


if __name__ == '__main__':
    app.run(debug=True)
```

3. Smart Contract Code (Solidity)

```
pragma solidity ^0.8.0;
contract FileVerification {
    struct FileRecord {
        string cid;
        address uploader;
    }
    mapping(string => FileRecord) public files;

    function storeFile(string memory fileId, string memory cid) public {
        files[fileId] = FileRecord(cid, msg.sender);
    }

    function verifyFile(string memory fileId, string memory cid) public view returns (bool) {
        return (keccak256(abi.encodePacked(files[fileId].cid)) ==
keccak256(abi.encodePacked(cid)));
    }
}
```

4. Deployment Code (deploy_contract.py)

```
from web3 import Web3
from solcx import compile_source

contract_source_code = '''[Solidity code above here]'''

compiled_sol = compile_source(contract_source_code)
contract_id, contract_interface = compiled_sol.popitem()

w3 = Web3(Web3.HTTPProvider("http://127.0.0.1:7545"))
w3.eth.default_account = w3.eth.accounts[0]

FileVerification = w3.eth.contract(abi=contract_interface['abi'],
bytecode=contract_interface['bin'])
tx_hash = FileVerification.constructor().transact()
tx_receipt = w3.eth.wait_for_transaction_receipt(tx_hash)
print("Contract deployed at:", tx_receipt.contractAddress)
```

5. Twilio Alert Only Code

```
from twilio.rest import Client

account_sid = 'YOUR_SID'
auth_token = 'YOUR_TOKEN'
twilio_number = 'whatsapp:+14155238886'
receiver_number = 'whatsapp:+8801XXXXXXXXX'

client = Client(account_sid, auth_token)
client.messages.create(
    from_=twilio_number,
    to=receiver_number,
```

```
body="Test WhatsApp Alert via Twilio"
)
```

6. IPFS Commands (CMD)

```
ipfs init --profile server
ipfs daemon
ipfs add test.txt
ipfs cat QmExampleHash
```

7. Postman Test Endpoint (Example)

POST http://127.0.0.1:5000/upload
form-data:
• file: (select file)
• file_id: abc123

POST http://127.0.0.1:5000/verify
form-data:
• file_id: abc123
• cid: QmYourCID

POST http://127.0.0.1:5000/verify_fake
(no params)

Appendix B: Plagiarism Report

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