Al-Azhar University
Faculty of Engineering
Computers & Systems Engineering Department

# Devault:

*A Blockchain-based, self-hosted, and end-to-end encrypted cloud storage.*

A Project Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Systems and Computers Engineering

*Submitted by:*

| | |
|---|---|
| **Abd El-Twab M. Fakhry** | *504055* |
| **Hossam A. Eissa** | *504042* |

*Supervised by:*

**Dr. Abdurrahman Nasr**

July 24, 2022

# Letter of Approval

The undersigned certify that they have read, and recommended to the Faculty of Engineering for acceptance, a project entitled “Devault: A Blockchain-based, self-hosted, and end-to-end encrypted cloud storage” submitted by **Abd El-Twab M. Fakhry** and **Hossam A. Eissa** in partial fulfillment of the requirements for the degree of Bachelor of Science in Systems and Computers Engineering.

Examiner Committee President:
Dr. Abdurrahman Nasr
Systems & Computers Engineering Department

Project Supervisor:
Dr. Abdurrahman Nasr
Systems & Computers Engineering Department

Examiner Member:
Dr. Abdurrahman Nasr
Systems & Computers Engineering Department

*Date of Approval:*

# Statement of Originality

This statement is to certify that to the best of our knowledge, the content of this thesis is our work. This thesis has not been submitted for any degree or other purposes.

We certify that the intellectual content of this thesis is the product of our work and that all the assistance received in preparing this thesis and sources has been acknowledged.

*Abd El-Twab M. Fakhry*
*Hossam A. Eissa*

July 21, 2022

**To the person who helped...**

# Acknowledgements

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Primarily, thanks to ALLAH (s.w.t), the Greatest, the Most Merciful, and the Most Gracious, Whose countless blessings bestowed upon me were kind, talented, and wise teachers, who provided me with sufficient opportunities and enlighten me towards this project.

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Thank You.

# Abstract

We propose a Decentralized Application (DAPP) that uses the Ethereum smart contracts for data access control and uses the InterPlanetary File System (IPFS) as a distributed system for storing and accessing data. Moreover, the files get encrypted on the client side using AES-256-CBC symmetric encryption and split into smaller chunks, distributed across multiple computers, and assigned a hash to allow users to locate them. Its then served to the user via a peer-to-peer connection, similar to BitTorrent technology.

Our proposed solution overcomes the problem of the centralized web, data censorship, data hacking, and data loss.

Keywords: *Blockchain; Cryptology; Peer-to-Peer Network; Decentralised Applications; Cloud Computing*

# Contents

# Chapter 1
# Introduction

## 1.1 Background and Motivation

Cloud storage has effectively replaced the traditional model of physical hardware storage for developers building apps and websites, as well as individual consumers storing their data. However, the centralized providers that provide cloud storage services have fostered a system with serious drawbacks like high fees, low flexibility, and a lack of alternatives. Thats where blockchain networks are working to improve upon the legacy model, striving to provide equitable decentralized cloud storage solutions that can better align the incentives of users and providers.

The internet now is governed by HyperText Transfer Protocol (HTTP). And Its how you access websites, watch videos, download files. There are some problems with it however, a lot of it stemming from the fact that the current model is largely centralized and this version of the web called Web 2.0.

Web 2.0 is the World Wide Web based on the concepts of social media, where the user can create content, post it online, and engage with other user-generated content. But the upcoming issue was that they did not own this content or the revenue being generated by it. The company that provided the platform for sharing the content has the maximum ownership of the revenue generated by that content. This led to the centralization of the data and traffic influence.

Web 3.0, unlike Web 2.0, has a decentralized distributed system. That means that all the nodes on the system in Web 3.0 have equal control and access. One of the key features of Web 3.0 is that it implements smart contract and Token using the Blockchain mechanism.

## 1.2 Problem Statement

Different cloud service companies ensure data availability and safety. However, they have “terms of use” that allow the company to edit, modify, access, delete, view, and analyze your content. And that to provide the best possible service to the client, create an advertisement, manipulate it in some way to generate income, or use it for their purpose or analysis.

However, storing sensitive data only on local machines or drives can sometimes be very lamenting because once they are lost or destroyed by any other means, you cannot make a recovery. Moreover, most of the personal accounts of cloud storage also do not cover the insurance of data or take responsibility in case of data loss due to catastrophic failure. So, relying on data stored on your local machine only or the cloud storage is just not always safe and genuine.

As for the protocol itself, when you want to visit a website today, your browser (client) sends a request to the servers (host) that “serve” up that website, even when those servers are across the globe from your current location. This is location-based addressing, and it uses Internet Protocol (IP) addresses to show your location. That process eats bandwidth, and thus costs us a lot of money and time. On top of that, HyperText Transfer Protocol (HTTP) downloads a file from a single server at a time, which is way worse than getting multiple pieces of that file from multiple computers. It also allows for powerful entities to block access to certain locations, like Turkey did with the Wikipedia servers in 2017.

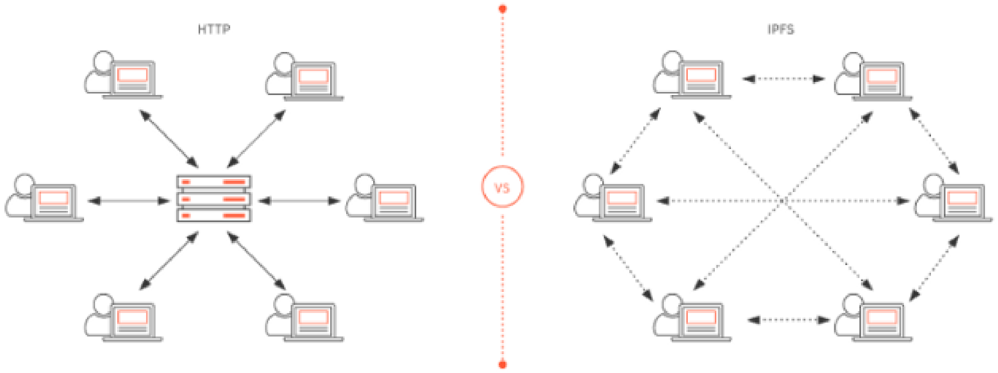


Figure 1.1: HTTP location-based addressing vs IPFS content-based addressing.

## 1.3 Aim of The Project

The project aims to design and implement a Decentralized Application that can store and retrieve files across the IPFS peer-to-peer network and uses the Blockchain as a public database. However, the Decentralized Application does not use traditional login. It uses a cryptocurrency wallet. Wallets give access to your funds and Ethereum applications. Only you should have access to your wallet. Moreover, we aimed to encrypt the files on the client side before uploading them so that it can prevent the data censorship and man in the middle attack.

On the other hand, the project aims to research cryptography, peer-to-peer networks, web technology, and Blockchain and to contribute to the active research on decentralized applications and cryptography.

## 1.4 Organization of The Thesis

The work in this thesis is organized as follows:

- `Chapter 1`: gives a brief background and motivation, states the problem we are addressing, and introduces the project aims.

- `Chapter 2`: is a literature review about the integration between cryptography, Blockchain, and IPFS. And it states the workflow throughout the project and the objectives in every milestone.
- `Chapter 3`: gives an overview of the software structure, how it works, and a detailed account of the implementation and testing.
- `Chapter 4`: assesses the success of our project and summarizes the achievements and deficiencies of the project.
- `Chapter 5`: suggests ideas and enhancements that can be done and implemented in the future and give a brief statement of how the solution we provided addresses the problem.

# Chapter 2
# Background Materials

## 2.1 Introduction

The current standard for digital data storage is called cloud storage. With cloud storage, users looking to host data, applications, and websites on the internet are reliant on centralized providers like Amazon, Google, and Microsoft to provide storage services. This method of storage  for which user data is stored on the centralized server farms of cloud storage providers  is often cheaper, more scalable, and more readily accessible across geographic regions than the previous standard of storage on physical hardware.

Cloud service providers allow developers to launch their applications more quickly, without worrying about setting up and managing servers, but customers typically have limited options in terms of providers and functionality. The majority of cloud storage providers are subsidiaries of bonafide tech giants and dominate the cloud services market, accounting for about 70% of the total market share as of 2021.

Despite their popularity and widespread use, many centralized cloud storage providers have been criticized for their tendency to force end users into inflexible and expensive cloud services and storage plans due to a lack of viable alternatives. Studies have shown that many developers settle for fixed amounts of hosting space that remain underutilized. This often results in hefty  and in many cases, unnecessary  premiums paid for cloud services.

That said, perhaps the biggest concern with centralized data storage models is that users are required to place trust in the central authority of the provider to keep their data safe, keep websites online, and not tamper with or censor the content that the centralized data providers host. In response, blockchain technology and decentralized networks have fostered a whole new methodology for digital storage: decentralized cloud storage.

In contrast to centralized, permissioned cloud providers, decentralized cloud storage providers leverage infrastructure that is designed to mitigate undue control or influence. These providers typically also utilize a permissionless structure that enables developers to employ their services with reduced restrictions. Conceptually similar to a decentralized blockchain, decentralized storage models draw their security from their widely distributed structure. This overall architecture can help make these systems more resistant to the hackers, attacks, and outages that have plagued large, centralized data centers.

## 2.2 Benefits Decentralized Cloud Storage

### 2.2.1 Encrypted

The nodes in a decentralized storage system are unable to see or modify your files since all data uploaded to a decentralized storage network is encrypted by default. As a result, you have unrivaled security and privacy, ensuring that your information is safe. Because of data encryption, nobody can access it without its unique hash. You can store personal and sensitive information without having any fear.

### 2.2.2 Secured

Decentralized data storage systems, provide a high level of security. They split the data into smaller chunks, produce copies of the original data, and then use hashes or public-private keys to encrypt each portion independently. The entire procedure protects the data from malicious parties.

### 2.2.3 Flexible Load Balancing

To make the process more efficient, blockchain-based decentralized storage systems allow the host to cache frequently-used data. It relieves server load and reduces network traffic. This eliminates the need for hosts to access the server on a regular basis to retrieve information.

### 2.2.4 Less Computer Power with Band Width

Decentralized cloud storage encrypts data, breaks it up, and distributes it for storage on drives. It is operated by various organizations in a variety of locations, each with its own power supply and network connection, creating something much less wasteful. A decentralized file storage system reduces both hardware and software expenses. You also dont require high-performance equipment to use it efficiently. More significantly, a decentralized network may include millions, if not billions, of nodes. This significantly increases the amount of storage space accessible. Decentralized data storage does not need high power consumption to run on the system rather it uses less computer power with Bandwidth.

### 2.2.5 No dedicated Servers for Storage

Decentralized cloud storage represents a paradigm shift to content-centric approach from a location-centric. One cannot access the database in decentralised cloud storage by just identifying where it is. Because data is distributed across a global network rather than being kept in a selected point, the principle of location becomes void in decentralised cloud storage.

Unlike centralized storage systems where a finite few data centers host your data, decentralized storage networks are composed of a series of nodes eager to host the data in a secure manner. It does not only offer a wider range of storage bandwidth, but it also reduces the overall storage cost, making it a cost-effective option.

### 2.2.6 Fast

It is commonplace to encounter network bottlenecks with centralized storage systems as the network traffic may sometimes overwhelm the servers. In a decentralized storage network, though, multiple copies of data are stored across various nodes. This eliminates the probability of network bottlenecks as you can access your data from a huge number of nodes, in a fast and secure manner.

Above were some of the advantages of decentralized cloud storage over traditional cloud storage which do not need any explanation. Seeing above advantages we can say that it can be future of cloud storage in coming years.

## 2.3 How Decentralized Cloud Storage Works

Working of distributed or decentralized cloud storage is very simple. All the workers or participating users are connected over a P2P network and stores data in a very secure and decentralized way. The files are broken into small data chunks, and intelligently distributed across many of the nodes which are located globally with the help of blockchain technology.

The users who participate in renting their extra storage capacity are paid via cryptocurrency and end users who use this space also pay in cryptocurrency and upload their data. So, there is no centralized governing body, who is holding all the data.

There is complete privacy in transmitting and storing the data as no third party is involved in between and each participating node only stores encrypted fragments of user data which the only user has authority to manage it through their own public/private keys. So, now the user has full control over their data because of blockchain technology used.

This network is highly secure, faster and less expensive than the traditional cloud storage and thus soon going to overthrow traditional cloud storage systems.

## 2.4 Methodology

### 2.4.1 Development Methodology

In this project we use both waterfall and scrum methodologies. We used the waterfall methodology for developing the smart contract because we can not update it once we deploy it. And for the rest, we used the scrum methodology.

Scrum, is a framework for project management, with an initial emphasis on software development, although it has been used in other fields including research, sales, marketing and advanced technologies. It is designed for teams of ten or fewer members, who break their work into goals that can be completed within time-boxed iterations, called sprints, no longer than one month and most commonly two weeks. The scrum team assesses progress in time-boxed daily meetings of 15 minutes or fewer, called daily scrums (a form of stand-up meeting). At the end of the sprint, the team holds two further meetings: the sprint review which demonstrates the work done to stakeholders to elicit feedback, and sprint retrospective which enables the team to reflect and improve.

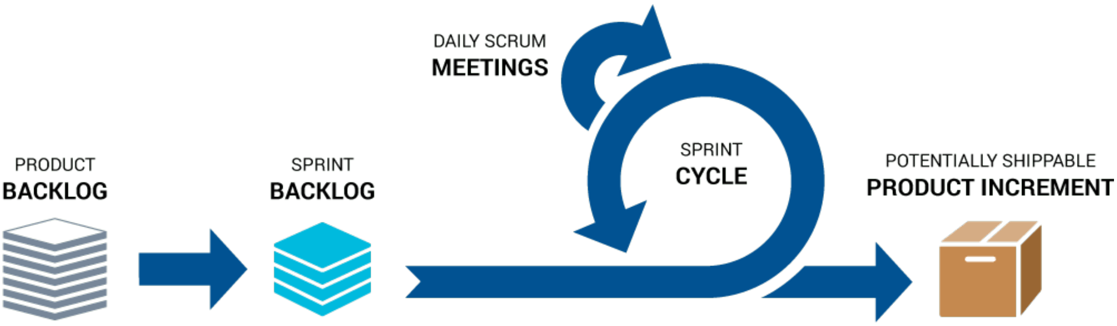


Figure 2.1: Agile scrum development process.

### 2.4.2 Use Case Modeling

A use case diagram is a graphical depiction of a user's possible interactions with a system. A use case diagram shows various use cases and different types of users the system has and will often be accompanied by other types of diagrams as well. In Devault the user can upload, download, share, delete, sort, and search files. Also the user can connect and disconnect their blockchain wallet.

#### Use Case Diagram

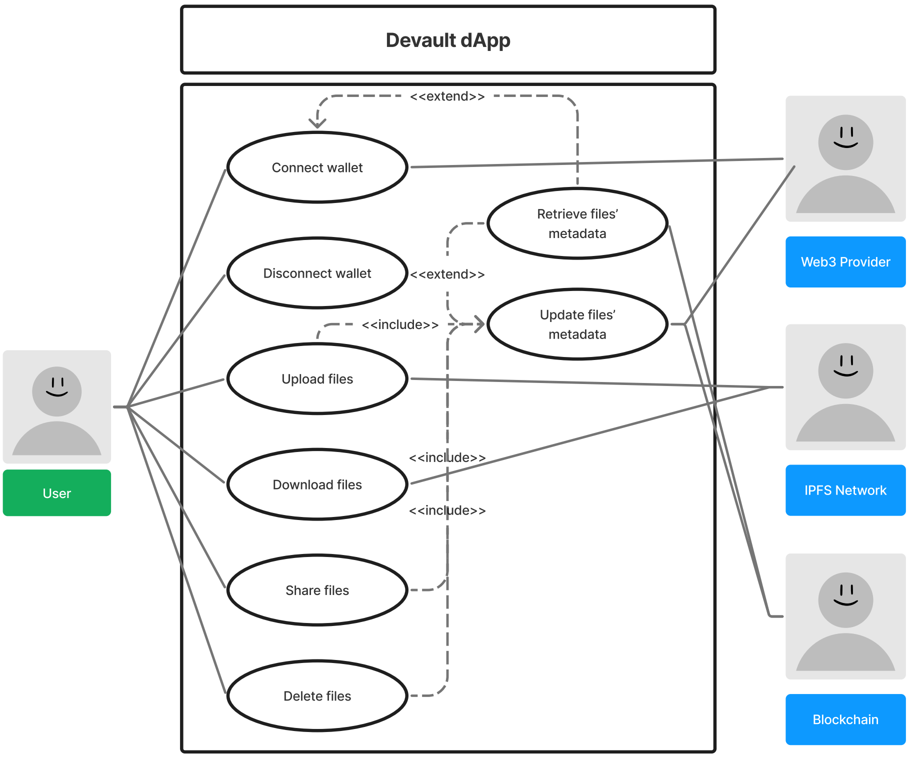


Figure 2.2: dApp use case diagram.

### Use Case Model

Table 2.1: Use case 1: Connecting wallet

| ID | UC_1 |
|---|---|
| Title | **Connecting wallet** |
| Description | The user can connect with their Ethereum wallet to use the system. |
| Primary Actor | User. |
| Pre-Conditions | • The user must have internet connection.<br>• The user navigates to `devault.vercel.app` or any other instance. |
| Main Success Scenario | 1. The user clicks the connect wallet button.<br>2. The user confirms the connection.<br>3. The system then will retrieve the files from that account. |

Table 2.2: Use case 2: Uploading files

| ID | UC_2 |
|---|---|
| Title | **Uploading files** |
| Description | The user can upload files or folders to the system. |
| Primary Actor | User. |
| Pre-Conditions | • UC_1 |
| Main Success Scenario | 1. The user navigates to the vault tab.<br>2. The user clicks on the upload button and picks a file or folder to upload.<br>3. The user enters a password to encrypt the files.<br>4. The system then will encrypt the files, store their metadata in the blockchain, and upload the encrypted files to the peer-to-peer network. |

Table 2.3: Use case 3: Downloading files

| ID | UC_3 |
|---|---|
| Title | **Downloading files** |
| Description | The user can download files or folders from the system. |

| | |
|---|---|
| Primary Actor | User. |
| Pre-Conditions | - UC_1 |
| Main Success Scenario | 1. The user navigates to the vault tab.<br>2. The user selects the files they need to download.<br>3. The user enter a password to decrypt the files.<br>4. The system then will decrypt the files and download them. |

Table 2.4: Use case 4: Sharing files

| ID | UC_4 |
|---|---|
| Title | **Sharing files** |
| Description | The user can share files or folders with other users. |
| Primary Actor | User. |
| Pre-Conditions | - UC_1 |
| Main Success Scenario | 1. The user navigates to the vault tab.<br>2. The user selects the files they need to share.<br>3. The user clicks the share button.<br>4. The user will be prompted to enter the addresses to share the file.<br>5. The system then will share the files with these addresses. |

Table 2.5: Use case 5: Deleting files

| ID | UC_5 |
|---|---|
| Title | **Deleting files** |
| Description | The user can Delete files or folders form the system. |
| Primary Actor | User. |
| Pre-Conditions | - UC_1 |

| | |
|---|---|
| Main Success Scenario | 1. The user navigates to the vault tab.<br>2. The user selects the files they need to delete.<br>3. The user clicks the delete button.<br>4. The user will be prompted to confirm the deletion process.<br>5. The system then will delete the files with form the user address. |

Table 2.6: Use case 6: Disconnecting wallet

| ID | UC_6 |
|---|---|
| Title | **Disconnecting wallet** |
| Description | The user can disconnect their Ethereum wallet from the system. |
| Primary Actor | User. |
| Pre-Conditions | • UC_1 |
| Main Success Scenario | 1. The user clicks the disconnect wallet button.<br>2. The system will log this user out. |

### 2.4.3 Class Diagram

A class diagram in the Unified Modeling Language (UML) is a type of static structure diagram that describes the structure of a system by showing the system's classes, their attributes, operations (or methods), and the relationships among objects. The following diagrams will show the class diagrams for the smart contracts.

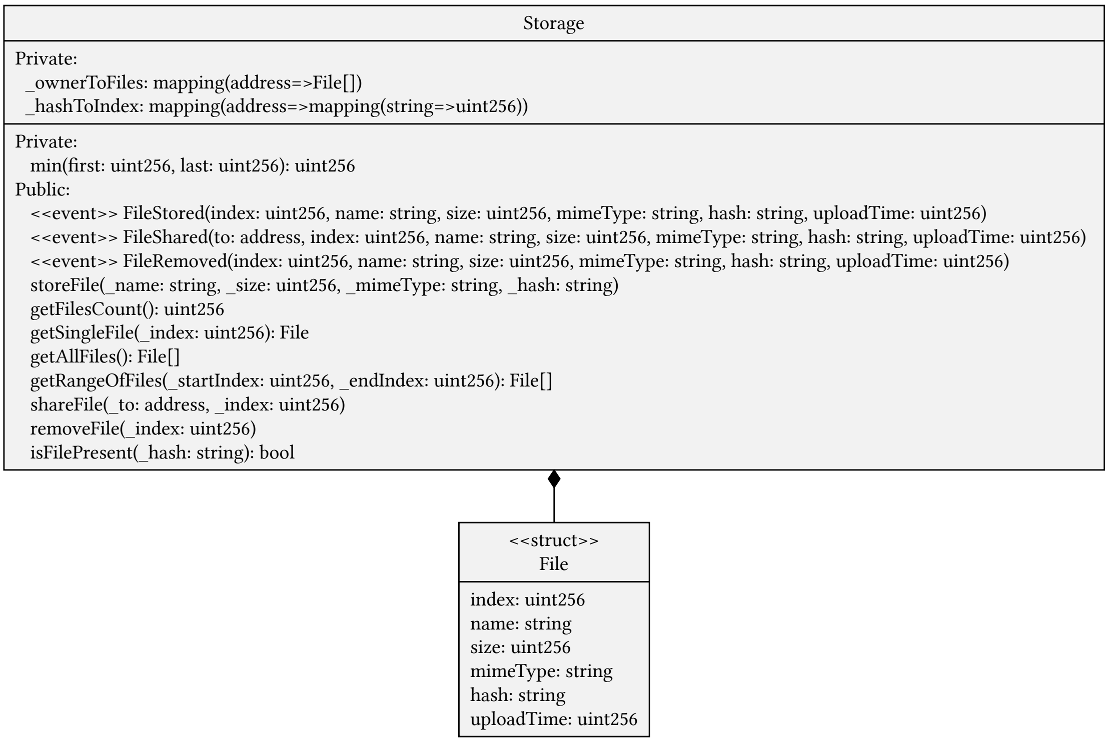

Storage
Private:
_ownerToFiles: mapping(address=>File[])
_hashToIndex: mapping(address=>mapping(string=>uint256))
Private:
min(first: uint256, last: uint256): uint256
Public:
<<event>> FileStored(index: uint256, name: string, size: uint256, mimeType: string, hash: string, uploadTime: uint256)
<<event>> FileShared(to: address, index: uint256, name: string, size: uint256, mimeType: string, hash: string, uploadTime: uint256)
<<event>> FileRemoved(index: uint256, name: string, size: uint256, mimeType: string, hash: string, uploadTime: uint256)
storeFile(_name: string, _size: uint256, _mimeType: string, _hash: string)
getFilesCount(): uint256
getSingleFile(_index: uint256): File
getAllFiles(): File[]
getRangeOfFiles(_startIndex: uint256, _endIndex: uint256): File[]
shareFile(_to: address, _index: uint256)
removeFile(_index: uint256)
isFilePresent(_hash: string): bool
<<struct>>
File
index: uint256
name: string
size: uint256
mimeType: string
hash: string
uploadTime: uint256

Figure 2.3: The smart contracts class diagram.

### 2.4.4 Sequence Diagram

A sequence diagram or system sequence diagram (SSD) shows process interactions arranged in time sequence in the field of software engineering. It depicts the processes involved and the sequence of messages exchanged between the processes needed to carry out the functionality.

The following diagram shows the interaction between the user, dApp, blockchain, web3 provider, and IPFS network.

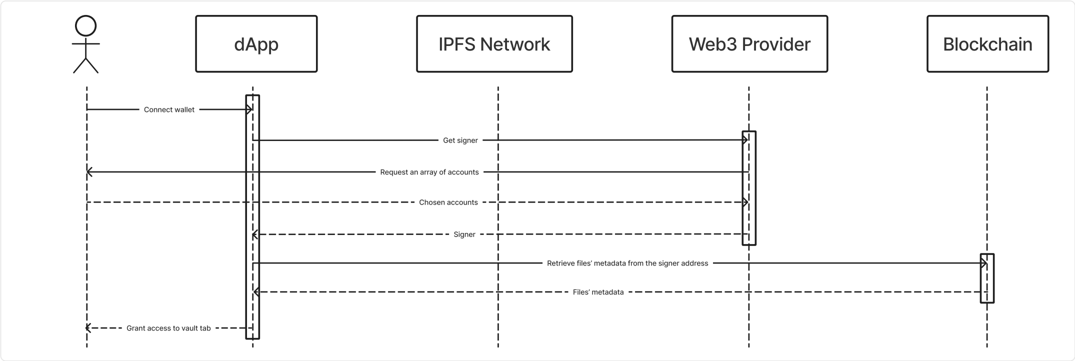

dApp
IPFS Network
Web3 Provider
Blockchain
Connect wallet
Get signer
Request an array of accounts
Chosen accounts
Signer
Retrieve files' metadata from the signer address
Files' metadata
Grant access to vault tab

Figure 2.4: Connect wallet act in sequential order.

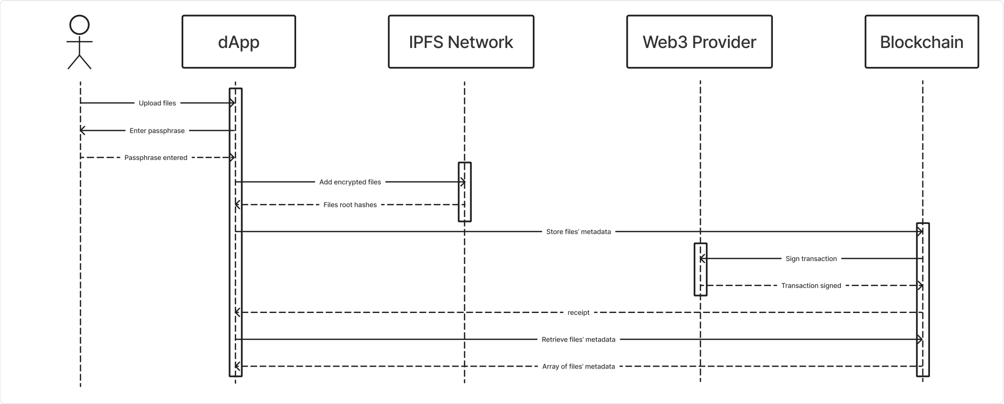


Figure 2.5: Upload files act in sequential order.

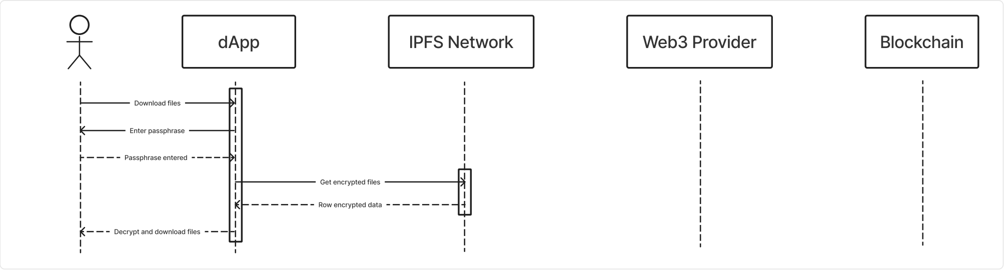


Figure 2.6: Download files act in sequential order.

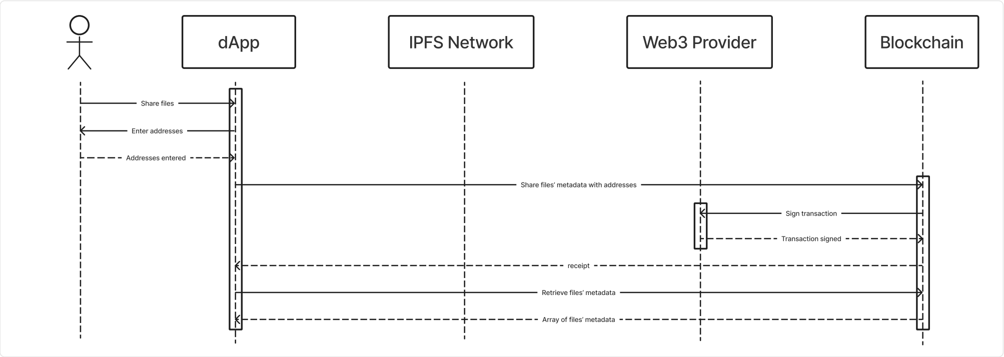


Figure 2.7: Share files act in sequential order.

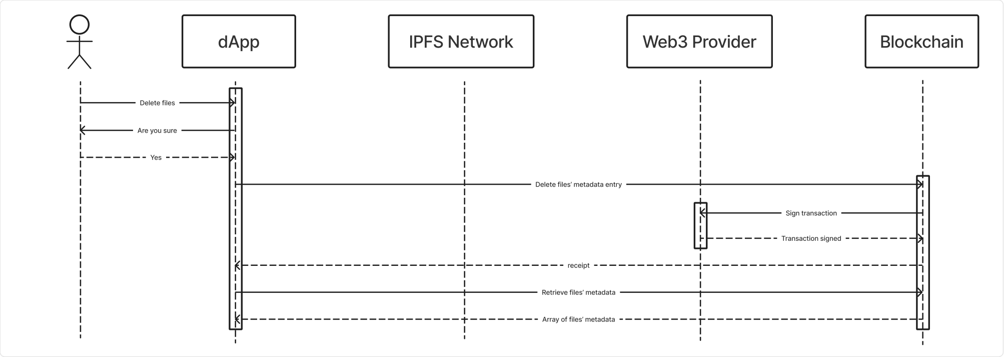


Figure 2.8: Delete files act in sequential order.

# Chapter 3
# System Design

## 3.1 Introduction

## 3.2 Implementation

### 3.2.1 Tools and Technologies

Table 3.1: Tools and technologies used in this project

| Tool | justification |
|---|---|
| JavaScript | JavaScript, often abbreviated JS, is a programming language that is one of the core technologies of the World Wide Web, alongside HTML and CSS. As of 2022, 98% of websites use JavaScript on the client side for web page behavior, often incorporating third-party libraries. All major web browsers have a dedicated JavaScript engine to execute the code on users' devices. |
| Next.js | Next.js is an open-source web development framework built on top of Node.js enabling React-based web applications functionalities such as server-side rendering and generating static websites. React documentation mentions Next.js among "Recommended Toolchains" advising it to developers as a solution when "Building a server-rendered website with Node.js". Where traditional React apps can only render their content in the client-side browser, Next.js extends this functionality to include applications rendered on the server-side. |
| Solidity | Solidity is an object-oriented programming language for implementing smart contracts on various blockchain platforms, most notably, Ethereum. It was developed by Christian Reitwiessner, Alex Beregszaszi, and several former Ethereum core contributors. Programs in Solidity run on Ethereum Virtual Machine. |
| Ethers.js | The ethers.js library aims to be a complete and compact library for interacting with the Ethereum Blockchain and its ecosystem. It was originally designed for use with ethers.io and has since expanded into a more general-purpose library. |

| | |
|---|---|
| Metamask | MetaMask is a software cryptocurrency wallet used to interact with the Ethereum blockchain. It allows users to access their Ethereum wallet through a browser extension or mobile app, which can then be used to interact with decentralized applications. MetaMask is developed by ConsenSys Software Inc., a blockchain software company focusing on Ethereum-based tools and infrastructure. |
| Hardhat | Hardhat is an Ethereum development environment. Compile your contracts and run them on a development network. Get Solidity stack traces, console.log and more. |
| IPFS | The InterPlanetary File System (IPFS) is a protocol and peer-to-peer network for storing and sharing data in a distributed file system. IPFS uses content-addressing to uniquely identify each file in a global name-space connecting all computing devices. |
| Docker | Docker is a set of platform as a service (PaaS) products that use OS-level virtualization to deliver software in packages called containers. We use docker for shipping and self-hosting the dApp. |
| Ropsten | Ropsten Ethereum (also known as “Ethereum Testnet”) is an Ethereum test network that allows for blockchain development testing before deployment on Mainnet, the main Ethereum network. Testnet ethers are separate and distinct from actual ethers, and are never supposed to have any value. This allows application developers or Ethereum testers to experiment, without having to use real ethers or worrying about breaking the main Ethereum chain. |

### 3.2.2 Code Documentation

```
/**
 * @dev Creates a new file.
 * @param _name Name of the file.
 * @param _size Size of the file.
 * @param _mimeType Mime type of the file.
 * @param _hash Hash of the file.
 */
function storeFile(
                   string memory _name,
                   uint256 _size,
                   string memory _mimeType,
                   string memory _hash
                   ) public {
    require(bytes(_name).length > 0, "Name cannot be empty");
    require(
            bytes(_name).length <= 512,
            "Name cannot be longer than 512 bytes"
            );

    require(_size > 0, "Size must be greater than 0");
    require(_size <= 2**30, "Size must be less than 2**30");

    require(bytes(_mimeType).length > 0, "Mime type cannot be empty");
    require(
            bytes(_mimeType).length <= 512,
            "Mime type cannot be longer than 512 bytes"
            );

    require(bytes(_hash).length > 0, "Hash cannot be empty");

    File memory newFile = File(
                                _ownerToFiles[msg.sender].length + 1,
                                _name,
                                _size,
                                _mimeType,
                                _hash,
                                block.timestamp
                                );

    // check if the file's hash is already present in the hashes array
    if (_hashToIndex[msg.sender][_hash] == 0) {
        _ownerToFiles[msg.sender].push(newFile);
        _hashToIndex[msg.sender][_hash] = _ownerToFiles[msg.sender].length;

        emit FileStored(
                        newFile.index,
                        newFile.name,
                        newFile.size,
                        newFile.mimeType,
                        newFile.hash,
                        newFile.uploadTime
                        );
    }
}
```

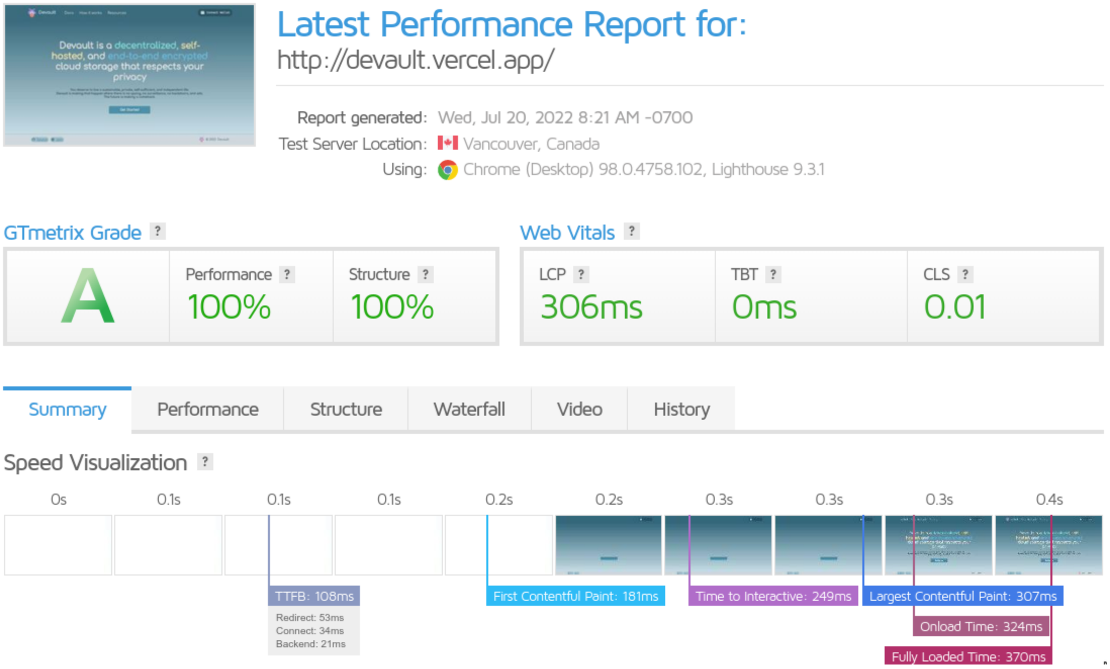
## 3.3 Testing

# Chapter 4

# Results and Discussion

## 4.1 Results

The current Devault v0.3.0 meets most original requirements, such as uploading, deleting, downloading, and sharing files. It supports brave wallet and metamask wallet.



Latest Performance Report for:
http://devault.vercel.app/

Report generated: Wed, Jul 20, 2022 8:21 AM -0700
Test Server Location: Vancouver, Canada
Using: Chrome (Desktop) 98.0.4758.102, Lighthouse 9.3.1

GTmetrix Grade: A
Performance: 100%
Structure: 100%

Web Vitals
LCP: 306ms
TBT: 0ms
CLS: 0.01

Figure 4.1: The performance report of devault generated by GTMetrix.

Table 4.1: The performance report details

| Performance Metrics | The measure |
|---|---|
| Total Page Size | 450KB. |
| Total Page Requests | 31. |
| Fully Loaded Time | 370ms. |
| Largest Content Element | 306ms |

## 4.2 Discussion

# Chapter 5
# Conclusion and Future Work

## 5.1 Conclusion

Blockchain is quite a buzz word right now, but once we really understand it and how it can make many applications we know and work with regularly more effective and efficient, well realize its true power.

All in all, a decentralized cloud storage app is more secure, faster, more efficient for file storage through apps like IPFS, and less costly to use than traditional decentralized file storage.

## 5.2 Future Work

1. Support Arabic language.
2. Use Shamir's Secret Sharing algorithms for sharing files.
3. Add the search functionality.
4. Compress files before uploading.
5. Enhance the ui/ux.
6. Manipulate selected files and folders.
7. Deploy to the mainnet.
8. Use Filecoin instead of IPFS.

# Appendix

# Glossary

## Acronyms

| | |
|---|---|
| **ABI** | Application Binary Interface |
| **ACL** | Access Control List |
| **AES** | Advanced Encryption Standard |
| **AIC** | Al-Azhar ICPC Community |
| **ASIC** | Application-Specific Integrated Circuit |
| **CBC** | Cipher block chaining |
| **CID** | Content Identifier |
| **DAG** | Directed Acyclic Graph |
| **DAPP** | Decentralized Application |
| **DHT** | Distributed Hash Table |
| **ETH** | Ether |
| **EVM** | Ethereum Virtual Machine |
| **HTTP** | HyperText Transfer Protocol |
| **IP** | Internet Protocol |
| **IPFS** | InterPlanetary File System |
| **nft** | Non-Fungible Token |
| **P2P** | Peer-to-Peer |
| **PoA** | Proof of Authority |
| **PoS** | Proof of Stake |
| **PoW** | Proof of Work |
| **SC** | Smart Contract |
| **TX** | Transaction |

## Terminology

**51% attack** When more than 50% of the miners in a blockchain launch an attack on the rest of the nodes/users to attempt to steal assets or double spend.

**ACL** In computer security, an access-control list (ACL) is a list of permissions associated with a system resource, also known as an object. An ACL specifies which users or system processes are granted access to objects, as well as what operations are allowed on given objects.

**bandwidth** bandwidth is a measurement indicating the maximum capacity of a wired or wireless communications link to transmit data over a network connection in a given amount of time. Typically, bandwidth is represented in the number of bits, kilobits, megabits or gigabits that can be transmitted in 1 second. Synonymous with capacity, bandwidth describes data transfer rate.

**Bitcoin** A cryptocurrency that uses a blockchain network to regulate the generation of coins/tokens and transfer of funds. Bitcoin is the most widely used cryptocurrency and is the most widely traded currency in the world.

**BitTorrent** BitTorrent is a communication protocol for peer-to-peer file sharing, which is used to distribute data and electronic files over the Internet.

**block** A block is a set of transactions that are recorded in a blockchain network.

**Blockchain** A blockchain is a distributed database that is shared among the nodes of a computer network. As a database, a blockchain stores information electronically in digital format.

**bytecode** Bytecode is the compiled code of a smart contract.

**centralized** A system or process for which there is a singular (i.e., central) source of authority, control and/or truth.

**chain** A chain is a sequence of blocks that are linked together by a hash of the previous block.

**CID** A Content Identifier (CID) is a self-describing content-addressed label used to point to the data stored in IPFS.

**consensus** The process used by a group of peers, or nodes, on a blockchain network to agree on the validity of transactions submitted to the network. Dominant consensus mechanisms are Proof of Work (PoW) and Proof of Stake (PoS).

**crypto keys** A public key is a unique string of characters derived from a private key which is used to encrypt a message or data. The private key is used to decrypt the message or data.

**cryptocurrency** Digital money which uses encryption and consensus algorithms to regulate the generation of coins/tokens and transfer of funds. Cryptocurrencies are generally decentralized, operating independently of central authorities.

**cryptography** The science of securing communication using individualized codes so only the participating parties can read the messages.

**Daemon** A Daemon is a computer program that typically runs in the background. The IPFS daemon is how you take your node online to the IPFS network.

**dApp** Software which does not rely on a central system or database but can share information amongst its users via a decentralized database, such as a blockchain.

**decentralized** A system with no single point where the decision is made. Every node makes a decision for its own behavior and the resulting system behavior is the aggregate response.

**DHT** A Distributed Hash Table (DHT) is a distributed key-value store where keys are cryptographic hashes. In IPFS, each peer is responsible for a subset of the IPFS DHT.

**digital signature** A mathematical scheme for verifying digital messages or documents satisfy two requirements - they have authenticity and integrity.

**Ethereum** A public blockchain that supports smart contracts.

**gas** A fee charged to write a transaction to a public blockchain. The gas is used to reward the miner which validates the transaction.

**genesis** The first block in a blockchain network.

**hash** A cryptographic hash function is a function that takes a message as input and produces a fixed-length output called a hash.

**HTTP** HTTP is a protocol for fetching resources such as HTML documents. It is the foundation of any data exchange on the Web and it is a client-server protocol, which means requests are initiated by the recipient, usually the Web browser. A complete document is reconstructed from the different sub-documents fetched, for instance, text, layout description, images, videos, scripts, and more.

**immutable** The property of being unchangeable. Once a transaction has been added to a block and written to a blockchain, it cannot be changed and therefore is immutable.

**IPFS** A peer-to-peer hypermedia protocol for the Internet. It is used to store and retrieve information in a decentralized way.

**IPFS Gateway** An IPFS Gateway acts as a bridge between traditional web browsers and IPFS. Through the gateway, users can browse files and websites stored in IPFS as if they were stored on a traditional web server.

**mainnet** The production version of a blockchain.

**Merkle Tree** A Merkle Tree is a specific type of hash tree used in cryptography and computer science, allowing efficient and secure verification of the contents of large data structures. Named after Ralph Merkle, who patented it in 1979.

**mining** In a public blockchain, the process of verifying a transaction and writing it to the blockchain for which the successful miner is rewarded in the cryptocurrency of the blockchain.

**node** A computer which holds a copy of the blockchain ledger.

**nonce** A nonce is an abbreviation for "number only used once," which, in the context of cryptocurrency mining, is a number added to a hashedor encryptedblock in a blockchain that, when rehashed, meets the difficulty level restrictions. The nonce is the number that blockchain miners are solving for. When the solution is found, the blockchain miners are offered cryptocurrency in exchange.

**off-chain** Data stored external to the blockchain.

**on-chain** Data stored within the blockchain.

**open-source** Software products that include permission to use, enhance, reuse or modify the source code, design documents, or content of the product.

**peer-to-peer** A direct connection between two participants in a system.

**pos** Proof-of-stake (PoS) protocols are a class of consensus mechanisms for blockchains that work by selecting validators in proportion to their quantity of holdings in the associated cryptocurrency. This is done to avoid the computational cost of proof-of-work schemes.

**pow** Proof of work (PoW) is a form of cryptographic proof in which one party (the prover) proves to others (the verifiers) that a certain amount of a specific computational effort has been expended.

**Satoshi Nakamoto** The name used by the person or entity who developed bitcoin, authored the bitcoin white paper, and created and deployed bitcoin's original reference implementation. As part of the implementation, Nakamoto also devised the first blockchain database.

**seed phrase** A random sequence of words which can be used to restore a lost wallet.

**smart contract** Self-executing computer code deployed on a blockchain to perform a function, often, but not always, the exchange of value between a buyer and a seller.

**solidity** Solidity is a programming language for smart contracts.

**testnet** A staging blockchain environment for testing application before being put into production (or onto the mainnet).

**transaction** A transaction is a set of instructions that are sent to a blockchain network to be processed by the network.

**trustless** The elimination of trust from a transaction.

**wallet** A digital file that holds coins and tokens held by the owner. The wallet also has a blockchain address to which transactions can be sent.

**Web 2.0** Web 2.0 is the World Wide Web based on the concepts of social media, where the user can create content, post it online, and engage with other user-generated content.

**Web 3.0** Web 3.0 is an idea for a new iteration of the World Wide Web which incorporates concepts such as decentralization, blockchain technologies, and token-based economics.

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# References

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