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Singapore Institute of Technology - University of Glasgow  
Joint Degree in Computing Science Degree Programme

CSC3001 Capstone Project

Please complete the following form and attach it to the Capstone Report submitted.

**Capstone Period:**   **07/09/2022 to 22/07/2022**

**Assessment Trimester: Final Trimester**

**Project Type: Academic**

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I hereby acknowledge that I have engaged and discussed with my Academic Supervisor on the contents of this Capstone Report (Literature Review) and have sought approval to release the report to the Singapore Institute of Technology and the University of Glasgow.

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| A picture containing graphical user interface  Description automatically generated  Singapore Institute of Technology - University of Glasgow Joint Degree in Computing Science Degree Programme |
| Final Capstone Report  Telemedicine Platform with Blockchain  For **Final Trimester** from **07/01/2022 to 15/04/2022**  *Tay Meng Yao Arthur*  *Student ID: 1901824*  *GUID ID: 2508403T* |
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| Submitted as part of the requirement for CSC3001 Capstone Project |

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# 1. Introduction

With the COVID-19 pandemic, women could not attend their pregnancy check-up appointments, affecting their access to antenatal care and health services, increasing constant fear and anxiety [1]. Everyday,Pregnant women are at risk of getting gestational diabetes mellitus(GDM), also known as GDM short, and it is a disease caused by high blood sugar levels present during pregnancy [2]. This disease may cause complications to the health of both mother and baby, such as birth injuries and respiratory distress syndrome, increasing the risk of high blood pressure [3] . However, there are ways to prevent or reduce the chances of gestational diabetes through healthy eating habits, exercising, and weight management, which pregnant women should be informed of [3].

## 1.1 Problem formulation

Not many pregnant women are aware of gestational diabetes in research and studies conducted. For example, in a research study conducted on the awareness of GDM for women, out of 141 women, only 58% of the women are aware of the disease, and only one woman could identify all four risk factors for GDM [4]. Shows a tiny proportion of women that knows all the risks of GDM. Based on another cross-sectional study, 403 pregnant women were recruited, only 125 women, 31 % of the participant, were aware of GDM [5]

Currently, this is also a problem that is trying to be solved by Gloobe Pte Ltd on the open innovation network portal, where the company states there is a lack of all-in-one platforms for gestational diabetes. There was also a concern about ensuring PDPA for users utilizing the digital platform. [6]. It’s essential to ensure PDPA for the health-related system, as noted. In 2018 there was a health data breach within SingHealth [7]. This incident caused severe damage to Singhealth, both finically and in privacy, with a considerable large amount of fines and leakage of 160,000 health records [8]. About 59% of records breaches were in healthcare in the US, and 28.8% of these records are due to unauthorized access and disclosure incidents. [9]

Globe is looking for a telemedicine platform; however, people have had concerns over data leakage of telemedicine due to data security and privacy concerns for telemedicine platforms where there is no trust in the technology. Most of these concerns were how the patient data was used and afraid of data leakage from unauthorized personnel [10]. A survey paper published online in September 2021 shows that e-health data concern is due to unauthorized access, data disclosure, tampering, and forgery. Data forgery could impersonate a service provider or doctor by data tampering, leading to data disclosure and unauthorized access to sensitive data. [11]. All this Data tampering and breaches can have a high consequence on an organization, in which attackers insert malicious files that could modify user credentials to gain access to sensitive data, which needs to be prevented [12].

## 1.2 Project Objectives

The aim of the project includes researching the feasibility of implementing architecture with blockchain to add security properties to healthcare data or user credentials in a Telemedicine platform created for gestational diabetes patients. Furthermore, access control is also an indispensable security solution to protect e-health data by restricting unauthorized access. [11]. The solution will target adding security properties for data integrity and protection by integrating technology such as blockchain to protect and verify data on atelemedicine platform for its access control. While possibility include healthcare features such asinformative consulting from doctor, which digitally provides healthcare from a distance, allowing pregnant women to easily safety access GDM information to improve awareness and care.

As noted in the cross-sectional study, the number of women able to identify all the risks of gestational diabetes is minor. Women would require a diet plan from an expert nutritionist. Allergies should be included or family health history too to allow for better diet planning. To prevent a similar situation occur with Singhealth, Blockchain could be used to implement to protect the health data. Blockchain acts as decentralised storage, increasing the difficulty of hackers penetrating the database and ensuring data privacy [13].

# 2. Literature Review

Further study is conducted to identify the feasibility of blockchain to be used as a database, the type of blockchain and the feasibility of creating a digital platform that acts similarly to telemedicine to interact with soon to be mothers.

## 2.1 Telemedicine and Information Access

Currently, telemedicine is an option for pregnant women to receive care in the pandemic, and it’s expected to reduce the risk of infection [14] and telemedicine platforms are expected to be the leading industry trend in 2021 due to the COVID-19 pandemic. [15] The amount of monthly active of telemedicine platforms grew by 272% from 2019 to 2021, and registered users have seen a 65% increase over the years [16]. Essentially shows the potential of a digital platform solution providing care and consultation at a distance. It’s also noted that most pregnant ladies obtained information from health care providers in GDM clinics, and at least 60% of GDM data were obtained from websites. [17]

## 2.2 Blockchain

Blockchain is distributed ledger technology (DLT) that stores information electronically on nodes in a network, maintaining a decentralized set of records. The information in blockchain technology allows data to be recorded and distributed, and it's immutable [18]. This Blockchain technology is used across various sectors such as healthcare, financial services, supply chain, etc. For example, blockchain targets healthcare by managing and protecting electronic health data [19].

There are mainly two types of Blockchain Permissionless and Permissioned Blockchain. The Permissionless Blockchain allows any user to participate on the node, known as the public blockchain. On the other hand, the permissioned type Blockchain is restricted and governed by single or multiple entities, also known as private Blockchain [20] [21]. The comparison between the two types of blockchains is seen in Table 1.

Table 1 Comparison Public and Private Blockchain

|  |  |  |
| --- | --- | --- |
|  | **Public Blockchain** | **Private Blockchain** |
| **Available Fabric** | **Ethereum** | **HyperLedger Fabric** |
| **Algorithm** | **Proof of Work** [22] | **Pluggable** [22] |
| **Smart Contract** | **Yes** | **Yes** |
| **Language** | **Solidity (JavaScript)** [22][23] | **ChainCode (JavaScript, Golang, and Java)** [22][23] |
| **Type** | **Permissionless** | **Permissioned** |
| **Applications** | **MedCredits** [24] | **MedicalChain** [25] |

Both Ethereum and Hyperledger Fabric utilized smart contracts; for Ethereum, it's known to be solidity, and for Hyperledger fabric, its chaincode [23]. This smart contract is a form of digital agreement that executes automatically after fulfilling a set of pre-programmed conditions [26] [27].

Compared to Hyperledger fabric and Ethereum on latency and throughput, the private Blockchain Hyperledger shows higher performances and consumes fewer resources [28]. Hyperledger fabric adopts a micro-services-based architecture with permissioned based capability to ensure privacy and provide flexibility for different modes of consensus such as Raft and Kafta [22]. In contrast to Ethereum's framework, Ethereum does not offer the flexibility of consensus algorithms solely utilizing proof of work, and transactions are publicly accessible, which will cause privacy flaws. However, Ethereum uses cases mainly involve financial and asset trading [22]. An Example of an Ethereum based healthcare application is Medcredits, used to automate the payments and validate the patients' transactions [29]. On the other hand, an example of Hyperledger fabric is Medicalchains, which are mainly used to support access control policy and securely share health data within the organisation [29]. Public Blockchain may seem to be better used for public verification purposes due to its transparency properties to gain trust of users who are concerned about how the data is being used. Private blockchains are meant for a private organization to other organizations' data consistency. Notability, there is also hybrid blockchain such as Dragonchain, a hybrid blockchain design consisting of a private blockchain network linking to a public network [38].

## 2.3 Database vs Blockchain Comparison

Table 2 Blockchain vs Database Comparison [30]

|  |  |  |
| --- | --- | --- |
|  | **Blockchain** | **Database** |
| **Authority** | **Decentralized** | **Centralized** |
| **Architecture** | **Peer to Peer** | **Client- Server Model** |
| **Data Handling** | **Read and write** | **Create, Read, Update, Delete** |
| **Data Integrity** | **Yes** | **No** |
| **Transparency** | **Transparent** | **Non-Transparent** |
| **Cryptography** | **Yes** | **No** |
| **Transaction Performance** | **Low** | **High** |

The main difference between blockchain and a database is the Authority; Blockchain is decentralized while the database is centralized. [30] Blockchain relies on Proof-of-work to write into the blockchain, which is necessary to prevent Sybil while writing into a database is immediate [31].In terms of performance, an average centralised database query speed is much faster compared to blockchain as database storage [32]. Databases are generally customizable to meet business requirements and have the stability of handling large volumes of data and processing thousands of transactions per second. In comparison to Blockchain, It has security properties such as hashing and data immutability to ensure data integrity. It provides the decentralization properties to ensure a fault-tolerant way to store and verify critical data, which is immutable, preventing tampering. In addition, it’s transparency to the public adds trust value to a system [31] [33] [34] Furthermore, blockchains prevent external and internal attackers from forging and tampering with data utilizing the time stamping method, which overwrites the tampered data to the original data [35]. This could prevent issues attackers from modifying user credentials to modify user credentials gain access to sensitive data.

However, data being transparent could lead to problems with storing sensitive data on the blockchain. But with, the combination of utilizing the immutability property of blockchain with the use of Crypto-privacy methods such as encryption ensures data privacy preservation and possibility resolves data being misused [36].

Databases examples are best for enterprise networks due to their stability in handling a large volume of data. Ideal for keeping confidential information and fast data processing [33] [37]. While use case examples for blockchain are establishing trust and transparency while providing security properties for transactions. Blockchain can be used for monetary transactions, verification of trusted data, essential verification, etc. [33] [37]. The data verification aspect may be used to ensure the data accuracy of the telemedicine platform shared between patients to reduce errors. This could be used to verify the user’s access role to ensure that there to ensure that only authorized healthcare roles can have access to particular data possibility reducing the likelihood of data breach of unauthorized access and disclosure incidents.

# 4 .Methodology/Proposed Design

Existing framework of health care blockchain

https://ieeexplore.ieee.org/abstract/document/8327543?casa\_token=DoUNcKP7K\_MAAAAA:o0fqa14wqaFmr6XU1zTmYYb5rBfmIlF24R9RFXBSapUwmm8HNYb\_IvXd1K8pt7yWrWRqEOgpcLR2UuM

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8038200/>

Web3 description.

https://hoangtrinhj.com/architecture-of-a-web3-application

## 4.1 Solution Architecture

Graphical user interface, application

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Figure 1 Possible Architecture

Telemedicine platforms have been trending and rising since the pandemic, showing the potential success of creating a digital platform providing care from a distance and information access catered to pregnant women with the integration of blockchain to secure and ensure PDPA. Through research, although blockchain may not seem ideal to store a large amount of data compared to a regular database, blockchain could still be used to ensure the role and access control with its tampered proof and verification aspect. In addition, it’s essential for webpage data processing to be fast; however, based on the above research, blockchain is slower than a database in terms of trasacation speed, as shown in Table 2. Which may not be ideal to to be used for an entire application data processing. To resolve this,the design proposed solution may adopt a hybrid database design approach for faster data processing and security properties from the blockchain to aid validation.

As seen in Figure 1, the SQL database will act as an off-chain database for other purposes, while the blockchain would verify specific data, such as access control.

Client

On the client side Ether Api library would be used to allow the client side application to easily interact with the etherum blockchain and the ecosystems[ https://docs.ethers.io/v5/] and the browser extension metamask is used to allow users to interact with the Ethereum blockchain and the application to manage their account keys and transactions.[ meta mask link]. The application will be developed with react as this framework unique properties of virtual dom allowing only components that changes to rerender and does not render everything making the website more efficient in terms of loading.[react virtual dom link].

Backend

Node express is used to create a rest api for the client to interact with the centralized postgresql database as a offchain datastorage. Solidity is used to develop the smart contract is a form of digital agreement that executes automatically after fulfilling a set of pre-programmed conditions[ ]. The contract will be compile using hardhat to the local simulated blockchain created by hardhat itself. All smart contract data interactions will be store in the local etheruem blockchain for validation purposes for the actual data in the centralized sql database.

## 4.2 Distribution of Token

<activity diagram>

For the access control portion of the telemedicine website. The solution will be using etherums tokens will be ultized to allow user’s to get access to the website based on the their roles. In the telemedicine system we have three roles. Patient which will be seeking consultation and doctors who will be providing the consultating and performing their expertise and Lastly Admin which will enroll the users.

|  |  |  |
| --- | --- | --- |
|  | **ERC20** | **ERC721** |
| **Token** | **Fungible** | **Non-Fungible** |
| **Interchangeable** | **Interchangeable** | **Non-Interchangeable(Unique)** |
| **Use Cases** | **Service vouchers, Governance token,etc** | **Artwork, Digital asset ,Property,** |

[https://www.blockchain-council.org/ethereum/erc20-vs-erc721/#:~:text=The%20main%20distinction%20between%20ERC20,Furthermore%2C%20ERC721%20is%20not%20divisible.] ERC 20

[https://www.nature.com/articles/s41598-022-05920-6]

The blockchain token in the solution will be ultizing ERC721 standard also known as non-fungible token(NFT). NFT are usually represented as artwork,digital asset or property and in this case the NFT would be used to represent the user account to act as an account token. Each token has a tokenID and unique properties and owner’s information. which uniquely identify and differentias itself from other token to help to uniquely identify each user.

[https://www.nature.com/articles/s41598-022-05920-6]

As NFT are part of the public blockchain implemented, owners of the NFT can easily verify the ownership of token as all transactions are transparents. The NFT data are immutable such as metadata,token id and transaction of the tokens are recorded in a distributed ledger or database which makes it impossible to change the information which is part of blockchains tamper proof aspect.This can aid fraud prevention for a user to impersonated a role to get access to sensitive records. [https://www.nature.com/articles/s41598-022-05920-6]

https://www.entrepreneur.com/article/403417

// blockchain tokens

https://medicalfuturist.com/nfts-an-health-data/

Currently an example how NFT are distributed can be seen in the Figure 2 below from a paper.

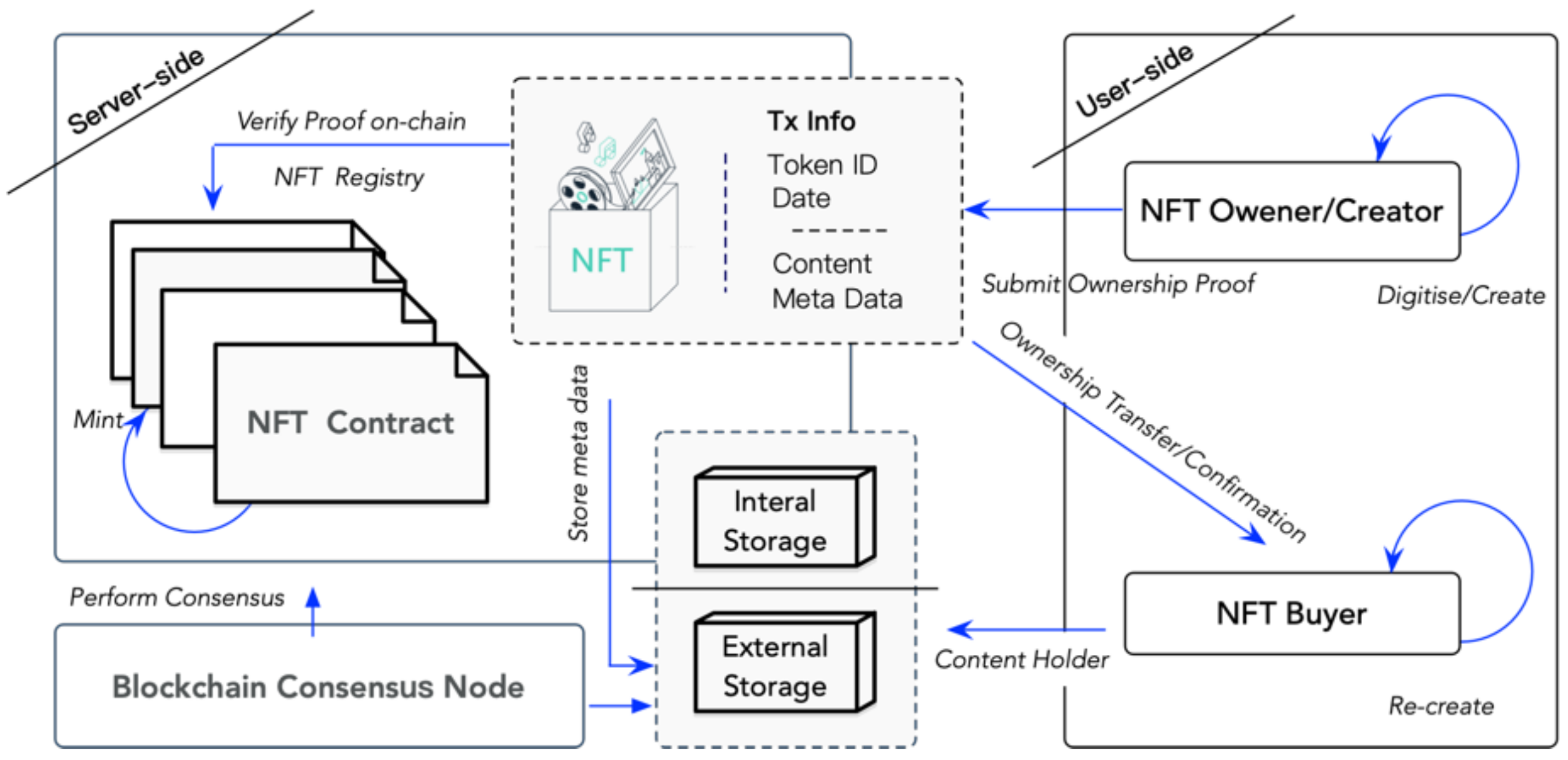


Figure Example of NFT Distribution[ ]

As NFT can be represented as Artwork, the original NFT owner would create the NFT and mint it into the blockchain and. The meta data of the token is then stored into an external storage and if a buyer buys the token, the ownership will be transferred over to the NFT buyer. The NFT Buyer would then posses the rights to do anything to the token that was brought based on their wallet address. [https://www.mdpi.com/2078-2489/12/9/358/html

]

For the solution process of distributing the NFT tokens is seen below

A picture containing timeline

Description automatically generated

Figure 3 Token Transfer Process

(talk about how we don’t want user to pay for the token, ) ( doctor/user are the buyer in this case but would not be paying) (NFT creator would be the Admin which will transfer the token to the user) compare to general NFT architecture.

## 4.3 Prototype

To show case the following setup and proceduces is done to show the the process of ultizing the blockchain and distributing the tokens.

1. (setup phase):The node js server api would be setup to allow the interaction of the postgresql database. The blockchain is setup using hardhard console which create a simulated local blockchain for the application to interact with. By running the “npx hardhat node”. With the local blockchain up a list of test account is displayed seen in the figure below.

2.(Smart contract Deployment)

With the blockchain and databased up.Telemedicine organization can deploy the smart contract to the blockchain and allow the minting of the token and transferring.

The smart contract is then deployed using a written javascript with the command

”npx hardhat run src/backend/scripts/deploy.js --network localhost”

There are 2 smart contract

* User- keep tracks of the accounts minted
* NFT- Minting the nft to the blockchain

For the instance take the owner of the contract to be this address “… “ from the test account created.

< show deployment of smart contract>

3 Registering: For the user to use the blockchain metamask would be required to connect to the blockchain and use the application.Once connected the user can begin registering and requesting for the token. Once submitted the form. It will be store in the centralized database.

<screenshot>

<database>

3:Admin: with the user’s info registered the Admin will be able to view the account request and help them enroll the the telemedicine website by minting the token for them.In this case the Admin would be the owner of the contract owner which deploys the smart contract. There are total of 4 interaction.

1. Mint token- mints the NFT token into the blockchain based on the user’s credentials
2. Setapprovalforall – as the owner of the token they would have to call this function from the ERC721 standard which will allow the token to be transferred.
3. CreateAccount- the function is from the
4. DistributeToken- this is then used to transfer the token to the user based on the user’s wallet adresss

<screenshot>

4. Receive Token- Lastly with the distribute token function token called the user will then received the token and be able to view it on the telemedicine website

# 4. Result and Analysis

Based on the prototype you can see the interaction of the smart contract, which were successful allowing the users to receive the tokens and visualize it on the application. Seen in figure X

(smart contract interaction)

(screen shot of demo result)

As the data are hashed, anyone can verify the data based on what the database reads. Each transaction that occurred are written in the block and can be seen that it has an hash. This ensures that blockchain is tampered proof where if someone tries to change the data, the entire block’s hash would change making it invalid. With blockchain been tampered proof, the hashdata stored on the blockchain can be used to verify the data in the centralized database giving it the validation properties. As long as the data computed from the centralized databased and the hash value in the blockchain does not match. The organization would be able to tell if the data has been tampered and revert the changes accordingly to the blockchain’s data. This would also aid in recovering the data that was tampered.

(show what happens when a hash is tampered)

(hardhat transaction on block hash)

(insert explanation of blockchain hashing)

However there is flaw in this process is currently before minting to the blockchain, the data might be tampered before minting which would require a way to secure the database itself. However once minted the validation could be done

# 5. Conclusion

<with the tamper proof

<talk about future work gas pricing regulation using L2 solution>

<talk about encryption>

<security database>

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