Towards a Secure Solution for COVID-19 Vaccines Distribution Based on Internet of Things and Blockchain

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Abstract— Internet of Things (IoT) is a key technological approach which has attracted the attention of researchers and scientists. It promises to change the way we are living, by its increasing solutions in all sectors such as healthcare, transportation, agriculture, logistics, etc. But despite these various practical applications, it is facing security and privacy issues, due to the centralization of existing systems creating a single point of failure.

Within two years the world has turned upside down due to Coronavirus disease 2019 (COVID-19), which has caused a global crisis, leading scientists from different countries to develop safe and effective vaccines that will help the humanity. In this context, the distribution and delivery of COVID-19 vaccines in a secure manner became a challenge. The current cold chain systems that are used to manage data related to the distribution and delivery doesn't offer transparency, traceability, immutability, and security. Moreover, they are vulnerable to cyber-attacks, especially if they are associated to IoT systems, which have a weakness in security controls. In this paper, we propose a reliable solution for COVID-19 vaccines based on IoT and Ethereum BC, to provide security and confidentiality of data related to the distribution and delivery of COVID-19 vaccines**.** We develop a smart contract to manage vaccines distribution process while ensuring transparency and security of data.

Keywords— **IoT; BC; COVID-19 vaccines; Cold chain; Ethereum; Traceability; Security; Smart contract**

I. INTRODUCTION

In recent years, we have witnessed the rise in the number of IoT devices, which are connected through cloud servers that provide huge data processing and storage capacities, but there are some concerns about IoT privacy and security. Sensitive information could be leaked on a very large scale, where IoT devices are acting as a potential access point for cyber-attacks , and this is one of the biggest challenges in all aspects. Thus, shifting the IoT systems to the decentralized path may solve some of the security and privacy issues of IoT. One of the popular decentralization systems is blockchain.

Blockchain has emerged in 2008, with the introduction of Bitcoin- a cryptocurrency by Santoshi Nakamota. Blockchain is essentially a database, a digital ledger of all transactions that is duplicated and shared across participating parties in the network.

The Integration of blockchain with IoT is getting more attention day by day, for instance, a smart device can function autonomously with no need for a centralized control, also security and privacy could be improved by the combination of these two technologies.. This paper focuses on integrating blockchain with IoT in the context of COVID-19 vaccines distribution and delivery to overcome some of the security issues in IoT.

The rest of this paper is organized as follows: Section II gives a background of internet of things, blockchain and its integration. Section III covers the summary of the litterature review. Section IV introduces the proposed system architecture. Section V presents the implementation of the proposed system and finally section VI is the conclusion.

II. BACKGROUND

A. Internet of Things (IoT)

Internet of Things is a new paradigm, that has been defined as an evolution of the Internet or a "New Internet", it is an emerged field in ICT (Information and Communication Technology), that allows interaction between the physical and the digital world, to connect to a wide range of networks without human supervision. Thus, this technological revolution has the potential to change each sector and every aspect of our lives to make it easier.

Basically, the IoT requires four important steps: 1) Collecting data about the surrounding environment using sensors. 2) Processing, storage and analyzing data at the cloud. 3) Taking decisions based on the result, and using data to enhance the productivity of smart applications as shown in Figure 1.

Fig 1: IoT ecosystem

B. Blockchain (BC)

Blockchain technology is among the most recent themes that changed the world of cryptocurrencies in recent years, it has attracted the attention of several organizations and researchers due to the countless benefits it provided over existing solutions [1].

Blockchain is fundamentally a distributed, decentralized and immutable ledger that ensures the transfer and storage of various transactions that have taken place in a certain P2P network [2]. Many people think that BC is just about cryptocurrency, but this is not true, its applications are in various other fields such as healthcare, supply chain and logistics, etc.

C. IoT and BC integration

The integration of upcoming technologies like IoT and BC has become a necessity to overcome the challenges of the centralized IoT architecture based on a cloud server. This integration has several features which are listed in Figure 2.

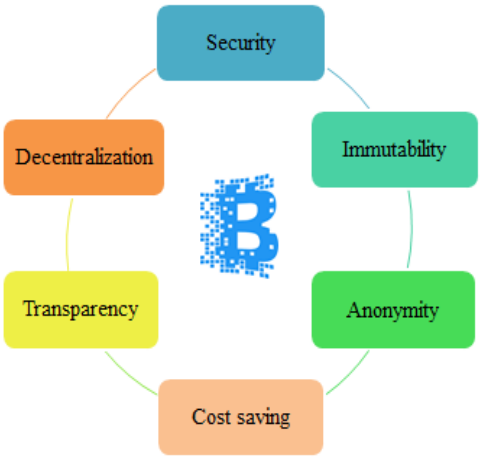


Fig 2: IoT and BC features

Decentralization: In a BC network, blocks can receive and store transactions without third-party intervention. Information is distributed, and nodes can participate in the transactions that take place in the decentralized system [3, 4]. Therefore this eliminates the centralized traffic flows and single point of failure of the current centralized IoT architecture.

Immutability: One of the key features of the blockchain is creating immutable ledgers; Any changes in the distributed ledger must be verified by the majority of the network nodes. Therefore, the transactions cannot be changed [5, 6].

Transparency: This is the most important advantage of the blockchain, which offers a high level of transparency in which all nodes have access to all the details of the transactions that ever happened in the distributed ledger without any changes since the content of a transaction is secured by the participant's private key. The transparency feature will enable various IoT devices to share data with other devices in the network and at the same time data integrity is guaranteed.

Security: is one of the main issues that stand in the way of successful deployment of IoT devices. But with integrating IoT with blockchain, this issue will be significantly reduced, as blockchain provides better security since it uses public key infrastructure that protects against malicious actions. The participating nodes of the blockchain network place their trust in the integrity and security features of the consensus mechanism. In addition, blockchain eliminates the single point of failure which affects the entire system [7].

Cost Saving: The **e**xisting IoT solutions are expensive because of the high infrastructure and management cost associated with centralized architecture. Since BC is a decentralized technology, it has the potential to reduce costs associated with installing and maintaining large centralized servers and other networking equipment. Adopting peer-to-peer communication to process billions of transactions between IoT devices will distribute computing and storage requirements across billions of devices that form IoT networks [8].

Anonymity: Although blockchain provides an invisible identity to protect the privacy of nodes. This feature has been criticised as it increases the use of cryptocurrencies in the illegal online market. However, it could be seen as an advantage if used for other purposes, for example, electoral voting systems [5, 9].

III. LITTERATURE REVIEW

Within two years, our lives has radically changed due to the outbreak of the pandemic of coronavirus disease (COVID-19), which appeared on November 16, 2019 in Wuhan, Hubei province (in central China), and has quickly spread around the world resulting a health and economic crisis. Various researchers, scientists and pharmaceutical companies have worked on identifying candidate vaccines to fight the spread of COVID-19.

Vaccination against COVID-19 is the only long-term solution in preventing the spread of infectious diseases. It is defined by WHO as "A simple, safe, and effective way of protecting people against harmful diseases before they come into contact with them. It uses the body's natural defenses to build resistance to specific infections and makes the immune system stronger" [10]. However, little attention has focused on how these

candidate vaccines truly reach the medical centers in a secure manner. This is very much an issue for the healthcare supply chain and area where integration of BC and IoT can be of great help.

The integration of Blockchain with Internet of Things has been explored in a few papers in this context. For example, authors in [11] proposed a blockchain based IoT system for COVID-19 vaccination which manages the registration of patients, storage, and distribution of the vaccines using smart contracts. In addition, the work in [12] Suggested a system which can be divided into the following two major contributions:

- Building an Internet of Things and blockchain based supply chain management for pharmaceutical drugs.
- Building scalable and secure high throughput blockchain distribution network (BDN) with the bloXroute server and Raft consensus algorithm that is suitable for IoT devices with high throughput.

In [13], Mark Treshock noted that one functionality of blockchain is helping with supply chain integrity at various touch points. Therefore, he said that blockchain has the potential to track the vaccines and make sure they haven't been compromised, furthermore, it can also be used to help patients keep track of their vaccine records and provide proof of vaccination for travel, schools and more. In another work in [14], the authors developed a "vaccine blockchain" system based on blockchain and machine learning technologies. Blockchain system is designed for the supervision of vaccine supply chains. Additionally, the use of machine learning models can provide valuable recommendations to immunization practitioners and recipients.

IV. PROPOSED SYSTEM ARCHITECTURE

The rapid deployment of a vaccine and the global vaccination campaign are essential, but its success, it will depend on the existence of a transparent supply chain that can be verified by all stakeholders.

A. Main Stakeholders of the system

The main stakeholders that contribute to our IoT-BC based system for COVID-19 vaccines, acting as Blockchain network nodes are:

- **Covid-19 vaccine Container**: is a vaccine carrier box that requires significant support to store vaccine at suitable conditions. IoT sensors can be embedded in vaccine carrier, along with a communication module to collect data, and analyze it.
- **Medical Center**: They will receive the vaccines and will need to do proper planning for their administration. In addition, they will have to find solutions to avoid identity fraud.
- **Vaccine Manufacturer**: the vaccine producers are required to follow defined standards in the COVID-19 vaccines data they provide. Each vaccine is carefully reviewed for safety, efficacy and pharmaceutical quality to determine whether it can be approved for use before distribution.
- **Vaccine Distributor**: continuously monitor vaccine delivery and transportation using IoT sensors.

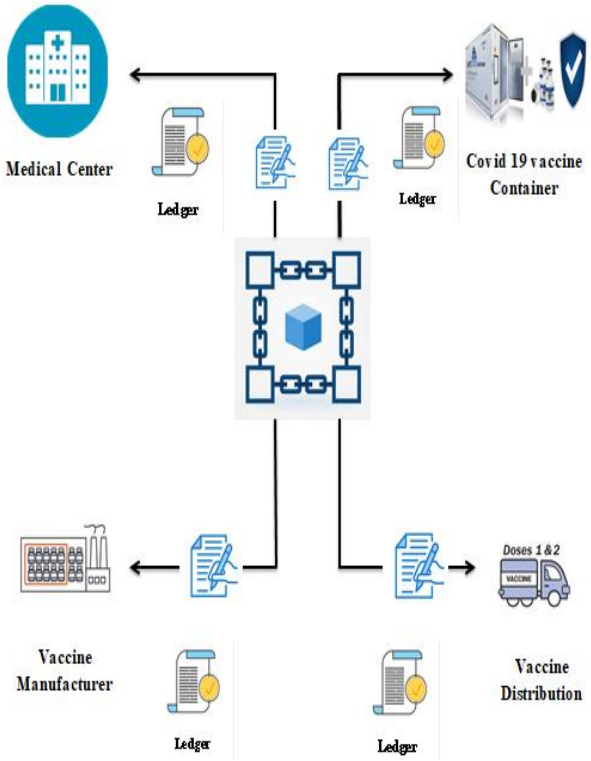


Fig 3: Stakeholders of the System

B. Proposed System

In this section, we present a secure system for COVID-19 vaccines based on IoT and Ethereum BC, to deliver safe vaccines to the medical centers. As shown in Figure 4 the steps of a cold chain

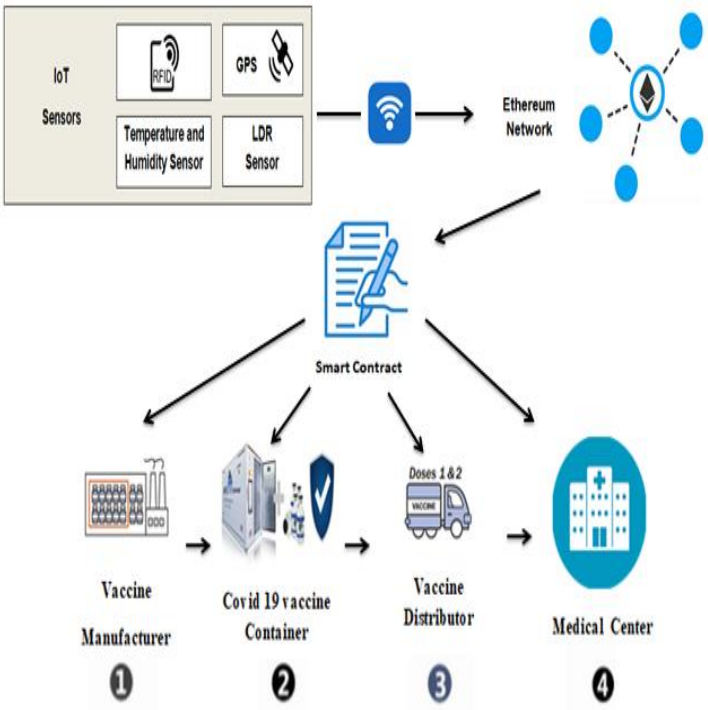


Fig 4: Proposed System

The benefits of our proposed system are:

- **Traceability**: During COVID-19 vaccines distribution and delivery, IoT sensors enable continuous monitoring of temperature, humidity, Light exposure and location of vaccines.

- **Security**: COVID-19 vaccines data are stored in Ethereum blockchain instead of cloud servers, to increase data security.

- **Data sharing**: COVID-19 vaccines data are shared across stakeholders of the system using a smart contract.

- **Authentication**: Each stakeholder control and authenticate vaccines data in Ethereum blockchain.

C. IoT-BC architecture layers based on the proposed system

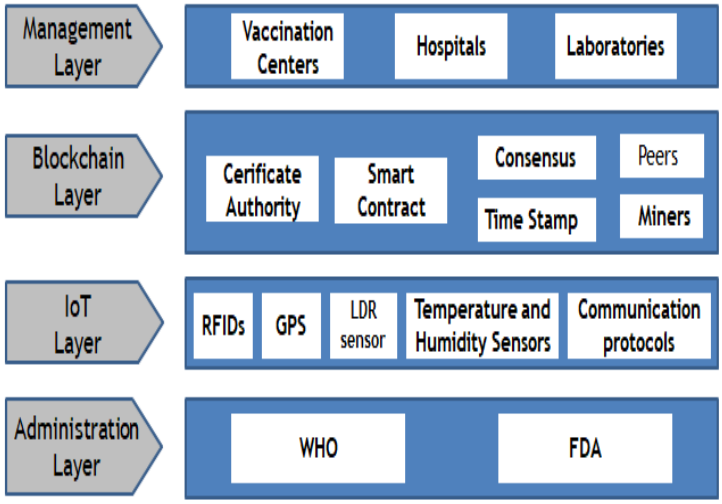


Fig 5: IoT-BC architecture layers of the system

Figure 5 illustrates the architecture layers of the proposed system as follows:

- **Administration layer**: which aims to approve COVID-19 vaccines by the World Health Organization (WHO) and the U.S. Food and Drug Administration (FDA)..

- **IoT layer:** Which is responsible for collecting data using radio frequency identification (RFID), a global positioning system (GPS), temperature and humidity sensors.

- **Blockchain layer:** Which plays a vital role in data security , it includes the certification authorities, smart contracts and other elements of the blockchain.

- **Management layer**: Vaccination centers, hospitals and laboratories manage the

distribution and delivery of COVID-19 vaccines.

V. SYSTEM IMPLEMENTATION

For implementing our system, we developed and deployed a smart contract on the Ethereum platform. There are several steps to develop and deploy smart contracts, generally, it can be divided into four steps: writing, testing, verification and deployment.

A. Development Tools and Environment

- **SOLIDITY**

Solidity is an object-oriented programming language for writing smart contracts. It is used to implement smart contracts on various blockchains, including Ethereum.[15].

- **REMIX**

Remix IDE (*Integrated Development Environment*) is a web application that can be used to *write*, *test*, and *deploy* Ethereum Smart Contracts [16].

- **TRUFFLE**

Truffle is a powerful framework that provides a suite of tools to develop Ethereum smart contracts with Solidity programming language.

- **GANACHE**

Ganache is a personal blockchain for local development. It enables to deploy smart contracts, develop applications and run tests. Ganache provides 10 Ethereum accounts with a balance of 100 ether (fake ether) for each account, as well as a graphical interface that allows us to examine everything that happens in this Blockchain.

- **METAMASK**

MetaMask is a software crypto-currency wallet used to interact with the Ethereum blockchain. It allows users to access their Ethereum wallet via a browser extension or mobile application, which can then be used to interact with decentralized applications [17].

B. Validation of the smart contract

In this part, we test and validate the developed smart contract. The evaluation is done by using Remix IDE, MetaMask and Ganache.

As shown in Figure 6, Ethereum addresses of the different stakeholders involved in the smart contract, as they are used throughout the COVID-19 vaccine distribution process.

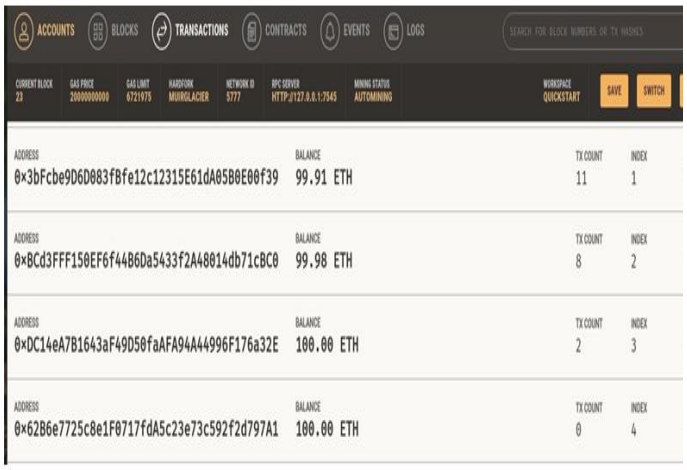


Fig 6: Ethereum address of different stakeholders.

C. Deployment of the smart contract

The deployment of the smart contract represented the main public functions as shown in Figure 7.

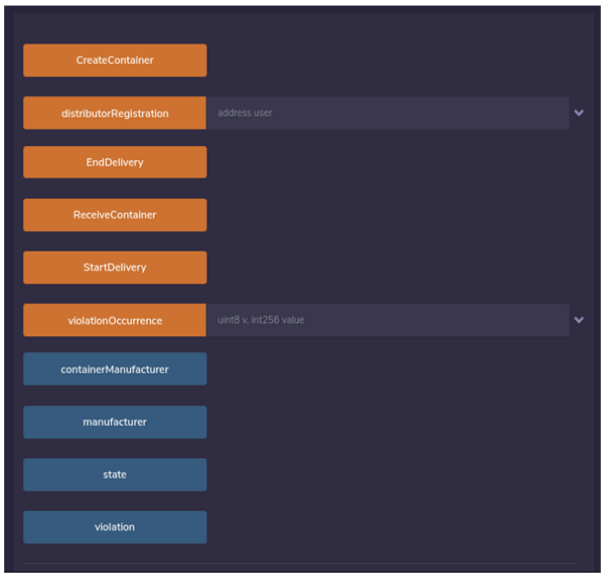


Fig 7: Functions of the smart contract

D. Tests and results of functions

- CreateContainer function

CreateContainer function indicates the creation of vaccines container, and prepare it for delivery .This function is executed by vaccines manufacturers. As shown in Figure 8, a validation interface of the transaction, and the cost required for the MetaMask registration of a candidate is 0.06 Ether with 20 Gwei as the price of a gas unit which is the average gas price in the MinNet.

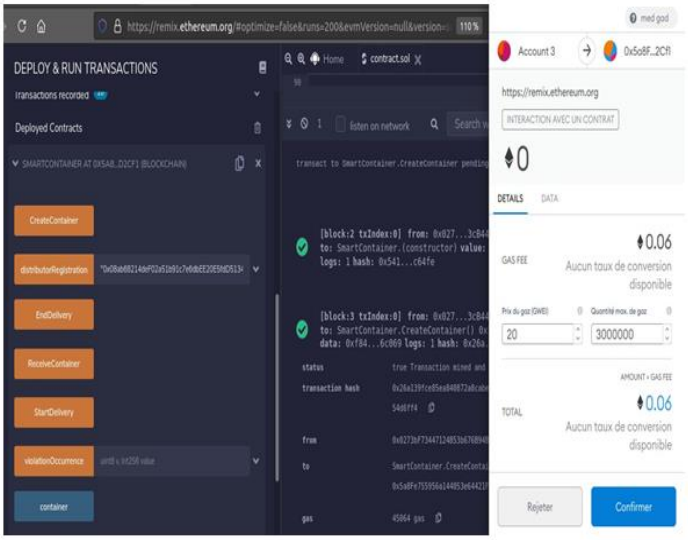


Fig 8: validation interface of the transaction

The results of the CreateContainer function are shown in Figure 9.

Fig 9: Successful execution of the function

- ContainerManufacturer function

ContainerManufacturer function aims to indicate the real manufacturer by using Ethereum address in the testing network. As shown in Figure 10, a validation interface of the transaction, and the cost required for the MetaMask registration of a candidate is 0.000901 Ether with 20 Gwei as the price of a gas unit which is the average gas price in the MinNet.

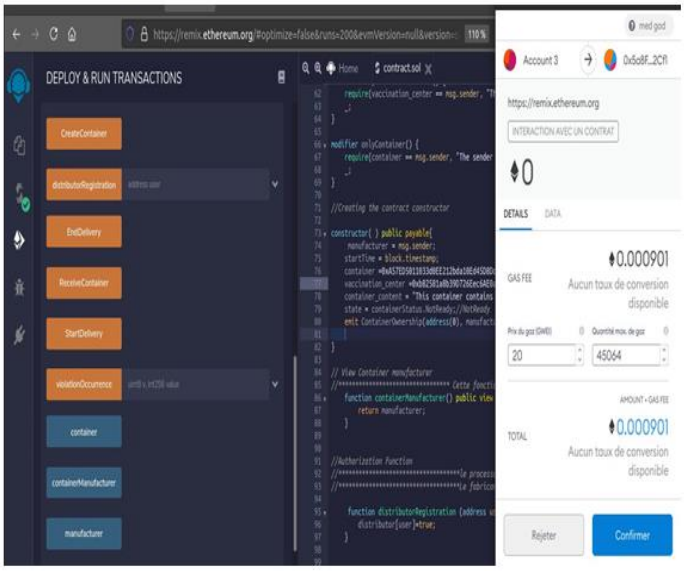


Fig 10: validation interface of the transaction

The results of the ContainerManufacturer function are shown in Figure 11.

Fig 11: Successful execution of the function

- DistributorRegistration function

DistributorRegistration function which aims to record the Ethereum address of vaccine distributor. This function is executed by vaccines manufacturers. As shown in Figure 12, a validation interface of the transaction, and the cost required for the MetaMask registration of a candidate is 0.000087 Ether with 20 Gwei as the price of a gas unit which is the average gas price in the MinNet.

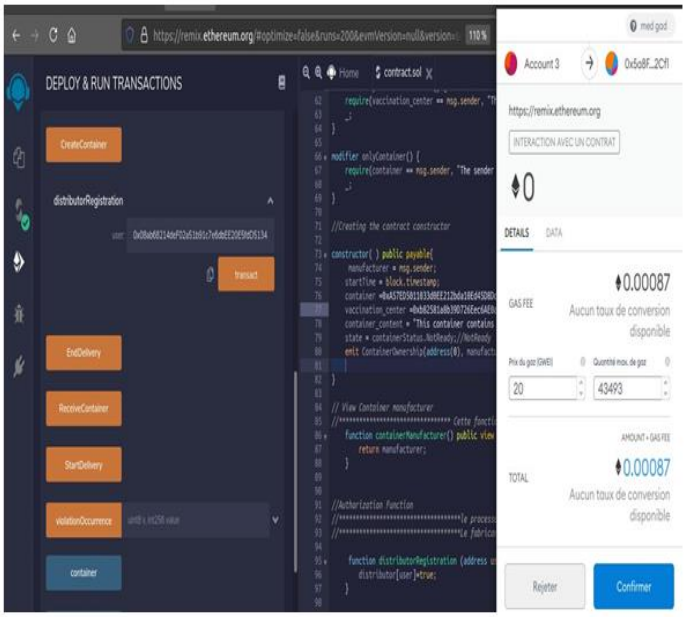


Fig 12: validation interface of the transaction

The results of the DistributorRegistration function are shown in Figure 13.

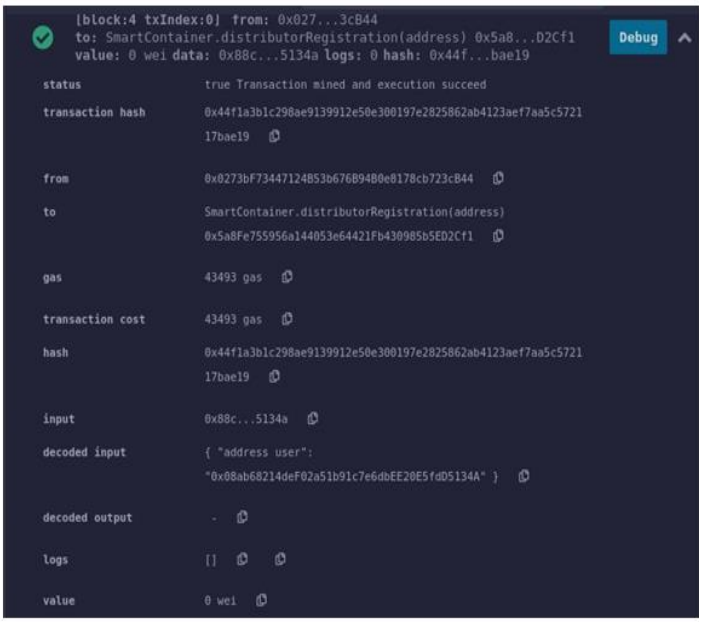


Fig 13: Successful execution of the function

- StartDelivery funtion

Before the execution of StartDelivery function, the container has to be in a suitable conditions for transportation of vaccines. , and for the execution of the function, it requires that the transmitter of the transaction has to be authorized to start the delivery of vaccines. Otherwise, the transaction will fail, and the delivery cannot be started. As shown in Figure 14, a validation interface of the transaction, the cost required for the MetaMask registration of a candidate is 0.000602 Ether with 20 Gwei as the price of a gas unit which is the average gas price in the MinNet.

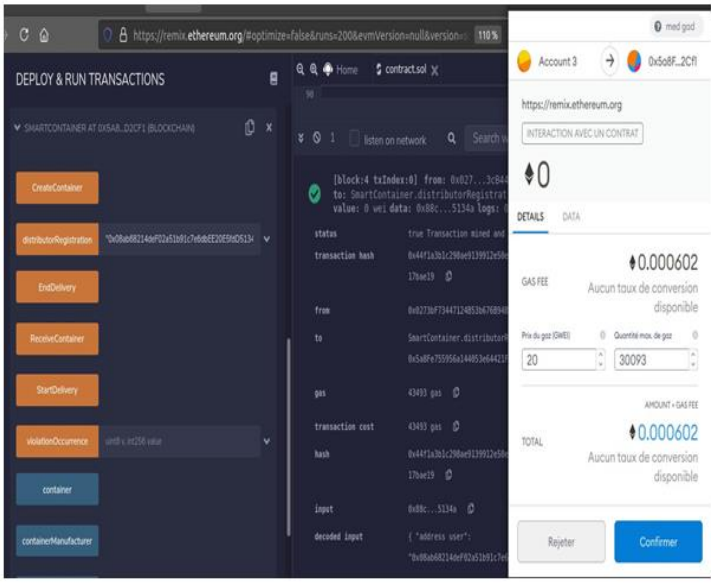


Fig 14: validation interface of the transaction

The results of the StartDelivery function are shown in Figure 15.

Fig 15: Successful execution of the function

- EndDelivery function

EndDelivery function indicates the end of the distribution and delivery of vaccines, and the container reaches the medical center. This function is executed by vaccine distributor. As displayed in Figure 16, a validation interface of the transaction, and the cost required for the MetaMask registration of a candidate is 0.000601 Ether with 20 Gwei as the price of a gas unit which is the average gas price in the MinNet

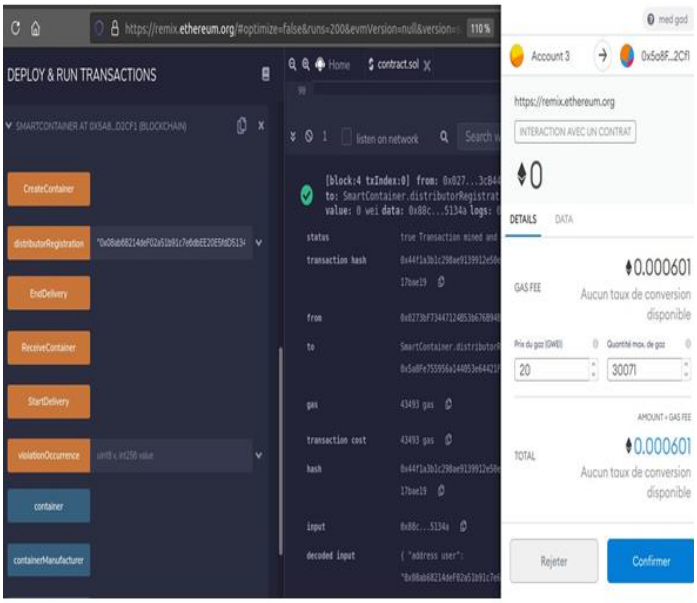


Fig 16: validation interface of the transaction

The results of the EndDelivery function are shown in Figure 17.

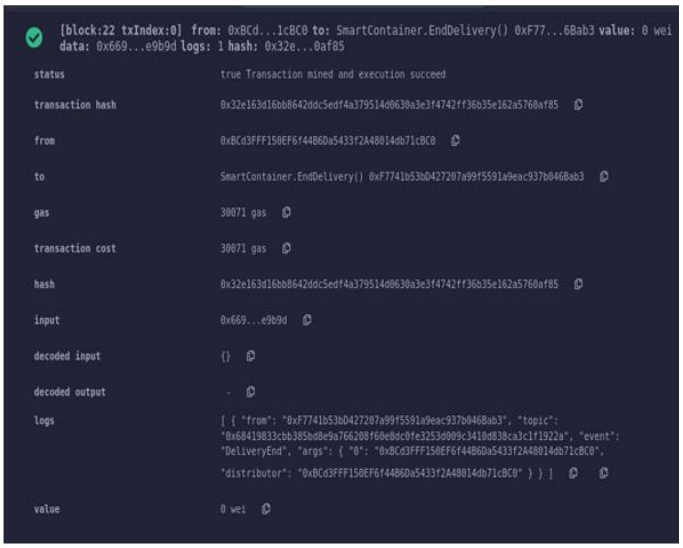


Fig 17: Successful execution of the function

- ViolationOccurence function

ViolationOccurence function is needed for violation tracking of vaccines container. This function is executed by vaccines container. As displayed in Figure 18, a validation interface of the transaction, and the cost required for the MetaMask registration of a candidate is 0.06. Ether with 20 Gwei as the price of a gas unit which is the average gas price in the MinNet.

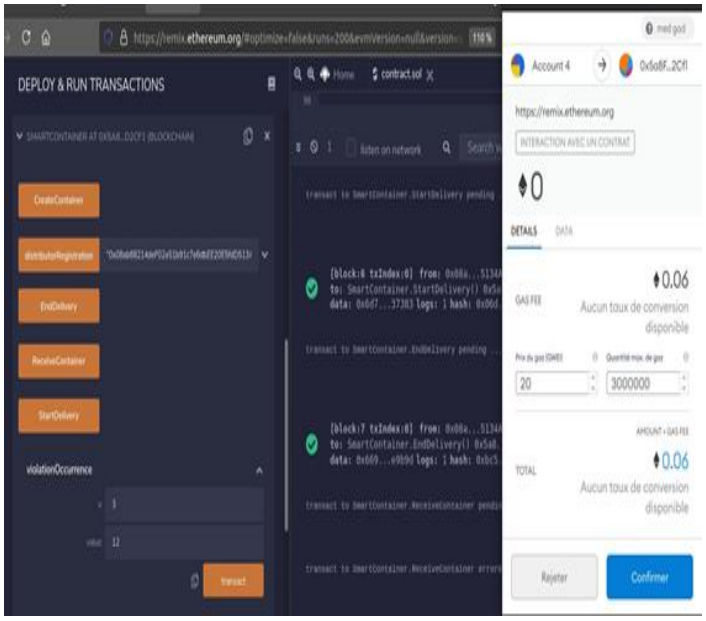


Fig 18: validation interface of the transaction

The results of the ViolationOccurence function are shown in Figure 19.

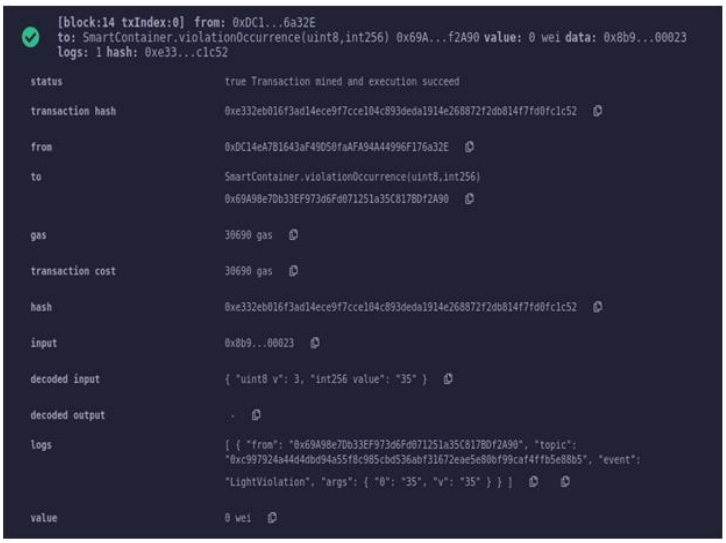


Fig 19: Successful execution of the function

- ReceiveContainer function

ReceiveContainer function refers to the arrival of vaccines container to the medical center. As displayed in Figure 20, a validation interface of the transaction, and the cost required for the MetaMask registration of a candidate is 0.06. Ether with 20 Gwei as the price of a gas unit which is the average gas price in the MinNet

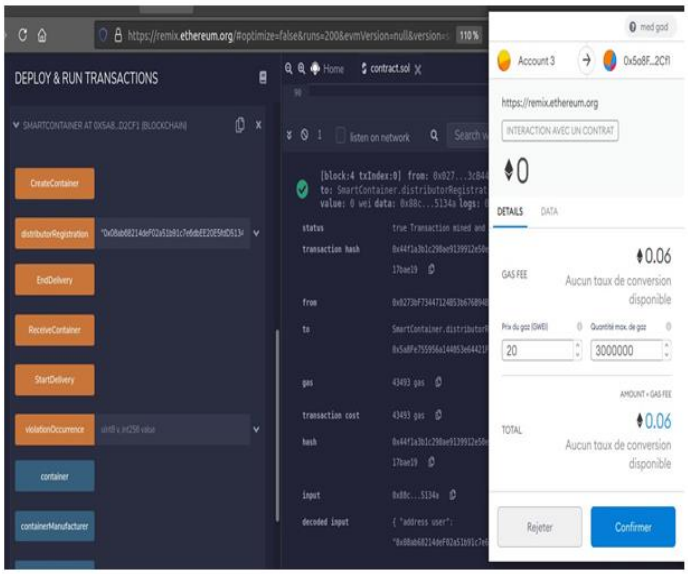
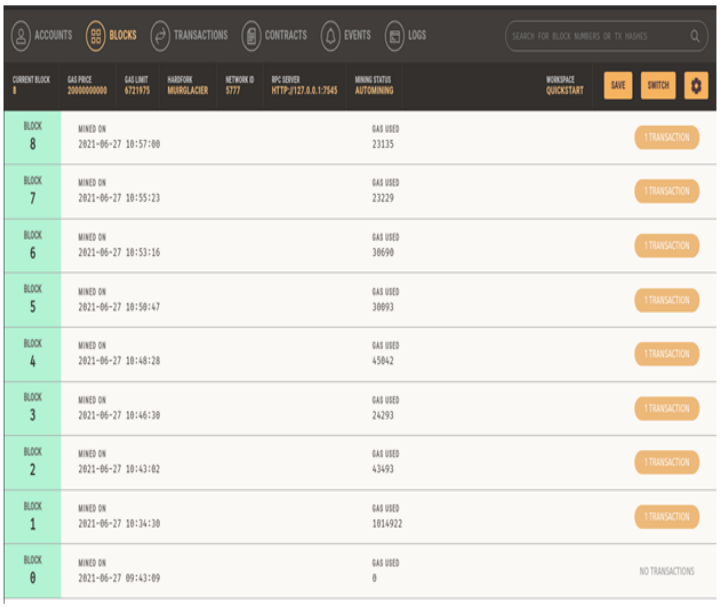


Fig 20: validation interface of the transaction

The results of the ReceiveContainer function are shown in Figure 21.

Fig 21: Successful execution of the function

Each transaction is written in the blockchain in a permanent and immutable way, and Figure 22 shows how the previous transactions looks like.



22: Transactions blocks in Ganache

VI. CONCLUSION

In this paper we presented an approach based on IoT and Ethereum BC for COVID-19 vaccines distribution and delivery. IoT enabled continuous monitoring of temperature, humidity, Light exposure and location of vaccines, while BC is used to offer data immutability, transparency and security for vaccines, using decentralized smart contracts.The immutability in our proposed solution can be a double-edged sword, because once vaccines data is stored on the blockchain, it will remains permanently and cannot be changed.

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