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Enhancing Healthcare Management during COVID-19: A Patient-Centric Architectural Framework Enabled by Hyperledger Fabric Blockchain

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Abstract: The highly transmissible COVID-19 virus has wreaked havoc on the global economy, health, and lives. The abrupt burst and exponential spread of this pandemic has shown the inadequacies of existing healthcare institutions in handling a public health emergency. As governments around the world strive to re-establish their economies, open workplaces, ensure safe journeys, and return to regular life, they require solutions to reduce losses. The proposed framework provides virtual assistance from various medical practitioners and physicians. Furthermore, it promotes the accuracy of information gathered from COVID-19 patients, which can aid in the launch of a variety of government decisions and public guidelines aimed at combating health exigencies. The authors present a revolutionary blockchain-based solution that builds trust between the medical professionals and patients while preventing accidental coronavisrus transmission. This solution also keeps track of COVID-19 patients and improves EHR management, which can be a viable solution for common EHR challenges such as lowering the risk of patient data loss, maintaining privacy and security, and obtaining immutable consensus on the maintenance of health records, gaps in hospital communication, and inefficient clinical data retrieval methods. This research work describes a COVID-19 patient-centric blockchain-based EHR employing JavaScript-based smart contracts for a decentralized healthcare management system. The proposed Hyperledger fabric and a Composer-based working prototype ensure the model's security and the authenticity of the health records. The authors used the Hyperledger Caliper benchmarking tool, which measures latency, throughput, resource utilization, etc., under different conditions and control parameters. The findings highlight the importance of the proposed blockchain-enabled architecture in revolutionizing healthcare administration during and after the COVID-19 pandemic, promoting enhanced clinical outcomes and supporting patient-centered care.

Keywords: blockchain; COVID-19; pandemic; Hyperledger; Caliper

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1. Introduction

Coronavirus has had an unprecedented impact on human life all over the world. Since this disease is extremely contagious, it has affected a substantial portion of the global population, resulting in a large number of infections and fatalities. COVID-19 has not only had an impact on human health but has debilitated the global economy as a result of strict countermeasures such as lockdowns that governments around the world have had to implement [1]. The intensity of the symptoms of COVID-19 varies from person to person, and they are comparable to the symptoms that are caused by the influenza virus. The most common symptoms of COVID-19 include exhaustion, cough, high fever, and shortness of breath. However, not everyone who has the disease will exhibit the signs of having it. Some people are considered to be “silent carriers” or “silent spreaders” because they do not exhibit any signs of the disease; nevertheless, such “carriers” pass it on to other people [2]. In addition, the disease has an extremely prolonged incubation period, which can persist for as long as a week and a half. Since the infected person might spread the virus during this time without showing symptoms, it is essential to build efficacious and reliable mechanisms for testing and tracing the possible cases of COVID-19. As is evident during the COVID-19 epidemic, everyone is anxious and searching for a virtual physician to examine the symptoms and reduce the danger of infection. Those who are infected with COVID-19, particularly those at greater risk of acquiring the disease (such as the elderly and those with underlying disorders), and those who are not affected both want to receive daily care without the risk of exposure to other hospitalized patients. In addition, layered structures in the reporting lines can result in variances, which can alter the overall response tactics and the efficacy with which they combat the disease. Therefore, unique and creative solutions are required to serve both the vital needs of COVID-19 patients and those of other individuals who require healthcare services. In this regard, technological advancements bring new choices [3]. To address such challenges, blockchain technology has offered a new model for application development.

Recently, several applications that are based on technology have been developed around the world to aid the authorities in closely monitoring public health as part of the fight against the COVID-19 pandemic. For instance, numerous business sectors, including Google and Apple, have lately introduced contact tracking applications that can assist the management in locating people infected with COVID-19. These applications can help in tracking down the affected individuals. However, the solutions that are now available require access to an individual’s personal data, such as their location and the results of their COVID-19 test, so as to determine the pace of viral propagation and anticipate viral hotspots within a community [4]. The majority of the systems that have been presented have implemented centralized architectures in order to gain access to COVID-19-related services and data and to store this information. Several contact tracing solutions make use of Bluetooth technology to determine whether or not a person had close contact with a patient who was infected with COVID-19 [5]. Because of the fact that contact tracing is a centralized solution that is managed, the service providers have access to the users’ data, which compromises the privacy of the data. In a similar vein, the data records and transactions stored in systems with a centralized location are susceptible to being altered, fraudulently altered, or deleted. In addition, decentralized systems are more reliable because centralized ones frequently have a single point of failure [6]. They have the potential to present a few options for collaboration across various organizations, such as those in the fields of healthcare, government, and law enforcement. Moreover, the centralized systems cannot provide full traceability, transparency, and immutability of the data that are kept and transferred during the different operational activities that are conducted to deal with the COVID-19 pandemic.

Various healthcare facilities save COVID patients’ health records in centralized databases (EHRs). EHRs must be shared often between hospitals, patients, and clinics. EHR distribution takes time and money. Cloud-based health data management addresses the issue of real-time data sharing and access [7]. One of the requirements for this kind of communication is that patient and hospital data should be in encrypted form before being transferred to the cloud, which uses plenty of random-access memory (RAM). Another author [8] presented a lightweight blockchain to overcome this problem by clustering healthcare network participants by demographics and keeping a single ledger per cluster. A framework based on blockchain technology for secure sharing of patient data could address the concerns about privacy and security [9–11]. Data encryption–decryption methods that are used to handle problems such as authorization of users, data confidentiality, integrity, record privacy were addressed by [12]. Similarly, ref. [13] deals with blockchain-based interoperability issues. Most experts suggest an Ethereum-based blockchain in the context of healthcare data because of its ease of deployment. Permissionless operations make it inefficient and insecure. It can affect processing power, scalability, and transparency but at the cost of scalability and privacy. Hyperledger is a new framework that offers a permissioned mode and fine-grained access control [14,15]. Hyperledger is a blockchain technology platform that allows for the secure and transparent storage and management of data. Consider a digital ledger or notebook in which information is collected in blocks. Each block carries data and is connected to the one before it, making a chain. What distinguishes Hyperledger is that it enables numerous organizations to collaborate and share this ledger, guaranteeing all individuals have the same information simultaneously. It fosters participant trust since data cannot be changed once recorded, assuring immutability and transparency. Hyperledger has been employed to improve procedures, increase efficiency, and develop confidence among stakeholders in a variety of applications, including healthcare, supply chain, and economics. Another researcher [16] advocated blockchain-based patient-centric healthcare solutions.

Several other techniques have been proposed, but none of them include an access control mechanism [17]. These proposed systems are intended to provide patients with a healthcare system that prioritizes patients' privacy. This solution, in particular, will be helpful in tracking COVID patients because it uses programmable smart contracts to run different function calls and create events that let participating entities know about patients' registrations, virtual physician appointments, dietician consultations, and other needs. We thoroughly examined the system's resource utilization, latency, throughput, and other key metrics, comparing it to conventional access control systems, to determine the effectiveness of our strategy. Through the following research questions, we endeavored to shed light on the potential of our proposed method to revolutionize the management and protection of sensitive healthcare data during the ongoing pandemic and beyond.

(1) What specific procedures are used to improve data security and privacy for COVID-19 patients in the proposed Hyperledger blockchain-based lightweight access control system?
(2) What are the essential components and design concepts of the architectural framework designed for the application, and how does it permit seamless integration with the Hyperledger blockchain to ensure effective access control for COVID-19 patient data?
(3) How does the proposed solution compare to standard access control systems in terms of resource utilization, latency, as well as throughput for managing COVID-19 patient data? What performance measures and benchmarks are utilized to assess the system's efficiency and scalability?

In this league, access control-enabled frameworks based on the Hyperledger framework have been designed and implemented via the network so that the users can access the data, which is referred to as declarative access control. The Hyperledger Caliper benchmarking tool can be used to perform evaluations regarding latency, usage of CPUs (central processing units) and memory, throughput, read and write performance. This work presents a patient-centric architectural framework that makes use of blockchain technology for the development of the next generation of healthcare applications. The model that is suggested in this work provides unparalleled access control to patients with effortless queries and also tracks their healthcare information. The authors of this proposed model have created a COVID patient-centric framework that not only ensures authenticity but also provides virtual assistance from physicians. It also encourages the accuracy of data collected from the COVID patients, and the same can be used to launch various government policies and decisions to combat any mass scale health emergency. In the case of COVID-19, the architectural framework will aid in preventing the accidental transmission of the virus. The envisioned novel blockchain-based solution that fosters trust between doctors and patients while eliminating fraudulent COVID test reports, as presented in this study, is a novel proposition.

The subsequent sections of this research paper are organized as follows: Section 2 provides an overview of the related works that have contributed to the development of the proposed framework. In Section 3, we present the detailed framework and system architecture that form the foundation of our solution. The deployment and implementation process of the proposed framework are elaborated in Section 4, outlining the practical steps taken to bring the system into operation. The results and performance analysis obtained from the implementation are discussed in Section 5, shedding light on the performance analysis of proposed solution and the key findings derived from the study and highlighting the implications. Section 6 deals with the discussion of proposed solution which has to understand the proposed solution aims to solve the problem and meet the objectives defined in the introduction section. Finally, in Section 7, we conclude the entire research study, summarizing the main contributions and discussing potential avenues for future research in this domain.

2. Related Work

In this research work, the authors examined and analyzed the key research conducted in the context of the COVID-19 pandemic, with a focus on the application of blockchain technology in combating COVID-19. Various applications based on a decentralized network have evolved since the introduction of blockchain technology so as to illustrate the usefulness and relevance of blockchain technology in healthcare. The authors of [18–23] studied how cutting-edge technologies can reduce COVID-19 illness spread. Here, the authors highlighted the importance of the Internet of Things (IoT), big data, blockchain technology, and artificial intelligence (AI) in developing simulation models that can properly anticipate disease spread. These technologies may also help us develop a screening tool for disease diagnosis and monitoring. The authors highlighted blockchain's use to track pharmaceutical deliveries [24]. This effort aimed to promote the use of cutting-edge technologies to contain COVID-19. Similarly, a low-cost blockchain and artificial intelligence-coupled self-testing and tracking system was recommended by [25,26] for COVID-19 and other emerging infectious illnesses.

On the other hand, refs. [27–29] noted how difficult it is to share medical information because the data may be erroneously modified and leaked throughout the operating procedure. This makes medical data transmission extremely challenging. It is likely that the confidentiality of the information will be jeopardized as a result of this. To address this scenario, the authors devised a method that featured a new consensus algorithm as well as an all-encompassing anonymous sharing architecture. Similarly, the authors of [30,31] proposed a method to anticipate the spread of COVID-19 and generate an immunity certificate to combat these outbreaks. Furthermore, ref. [32] developed a permissioned blockchain-based healthcare architecture to increase access to data among the healthcare providers by utilizing policies of access control to facilitate data sharing. This study reported that it has a synergistic relationship with the work described in this research work. However, a few new modules, particularly the chemist and insurance, were introduced in this effort, and their interaction with the rest of the design was fundamentally altered as a result. A system like this will allow the insurance companies to register, authorize, verify, and disburse claims in a simple and fast manner while ensuring that the claims are valid. This is only one example of an insurance circumstance, and there are many more that may occur. Furthermore, in contrast to the study published by [33], the entire framework design of this research work follows the principle of patient-centric design philosophy. The envisaged mechanism would allow the patients to access their data when they need to. For example, the patient's records can be made available even after the patient has been discharged and across a variety of time frames, hospitals, and other settings. This is where the originality of the work offered above is found. Thus, the work presented herein is unique. Although a few studies have focused on COVID patient-centric healthcare systems, none of these studies has yielded complete data on how they were implemented or how effectively they functioned from the beginning to the end.

Despite the fact that a variety of different approaches to utilizing cutting-edge technologies such as blockchain to facilitate a COVID-19 response have been investigated, the existing efforts do not present any technical details, with the exception of [34], in which the authors proposed a novel patient-centric architectural framework for blockchain-enabled healthcare applications. In addition, the methods described above do not demonstrate a mechanism for preventing the further propagation of the COVID-19 virus by the direct application of blockchain technology. Most of the research available in the literature either offers blockchain as a potential technology to halt the dissemination, suggests that blockchain can assist in stopping the spread of incorrect information, or suggests that blockchain can be used in conjunction with other technologies to present a framework. None of the researchers proposed and carried out an implementation of a blockchain-based solution that can assist in the tracking and tracing of COVID-19 test-buyers that possesses the following properties: data privacy, security, accessibility, availability, and interoperability. In addition to presenting the implementation and performance evaluation of the suggested scheme, the current study has the ability to address the aforementioned problems. The following are the most significant contributions of this study:

(1) The study proposes a Hyperledger blockchain-based, lightweight access control system for COVID-19 patients.
(2) The study enlists the design and development of an architectural framework for such an application.
(3) The study demonstrates the effectiveness of the suggested method in terms of resource utilization, latency, and throughput, among others.

3. Proposed Framework and System Architecture

In this research work, electronic healthcare architecture based on blockchain technology is proposed for COVID patients, as shown in Figure 1. It depicts important segments and their relationships to the proposed healthcare system developed for patient-centric EHRs for COVID patients. This proposed system is composed of different sections that are represented by rectangular boxes. Providing a common data sharing platform, the proposed framework will benefit the healthcare system's differing participants. Each participant can retain health data on a network of computers using blockchain. Using a blockchain API (Application Programming Interface), each of these components is able to communicate with other participants in the blockchain and regulate the blockchain's state by dealing with transactions that update each participant's ledgers. As illustrated in Figures 2–5, it is made up of five software components, each of which has a detailed depiction.

The first module (participant module) is majorly concerned with the creation of secure, decentralized, and immutable electronic health records. It involves different stakeholders, such as the virtual physician, patients, pharmacist, pathology, and dieticians. The next module is concerned with all the assets that ensure EHR consistency among the different participating institutions and with enabling patients to consent to share their EHR data. The final module contains the remaining transaction and access control functionalities, which include the ability to retrieve a patient's complete health record, the ability to easily verify medical prescriptions, and the availability of EHRs for all participants that provide transparency of patient data.

Section 3.1 describes the system architecture, Section 3.2 describes the assets and participants in the proposed model, and Section 3.3 describes the interaction among participants.

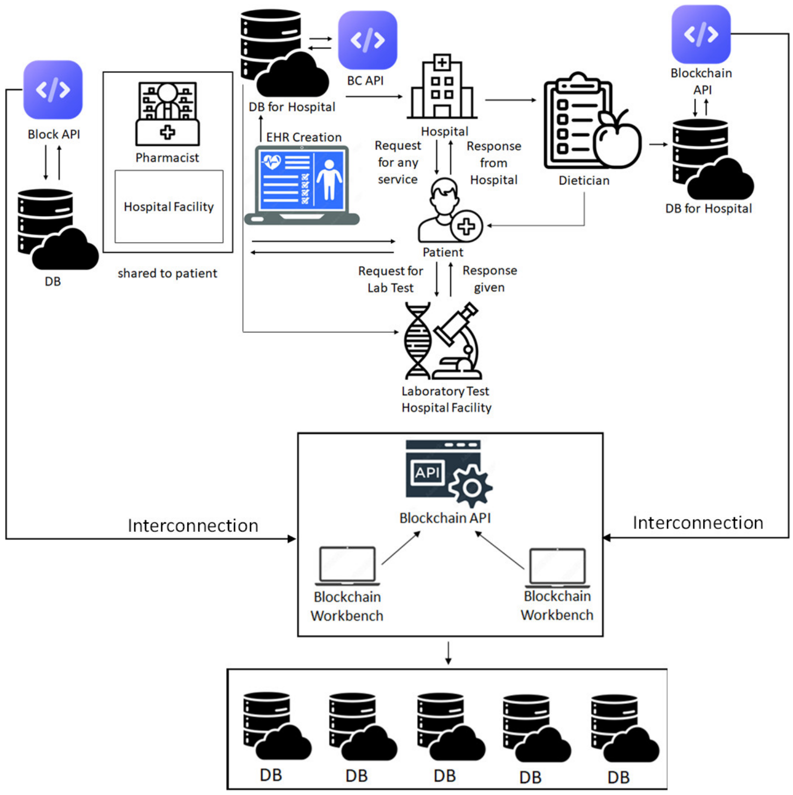

Figure 1. Blockchain-Enabled Healthcare COVID Patient-Centric Architecture.

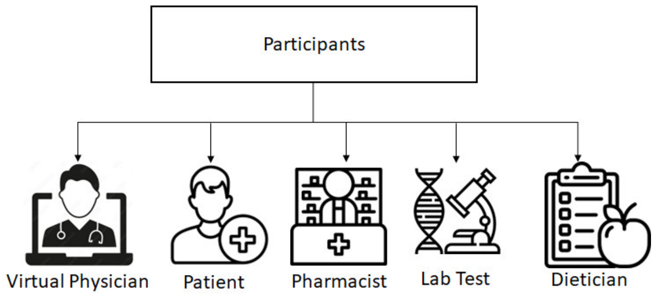

Figure 2. Participant Module.

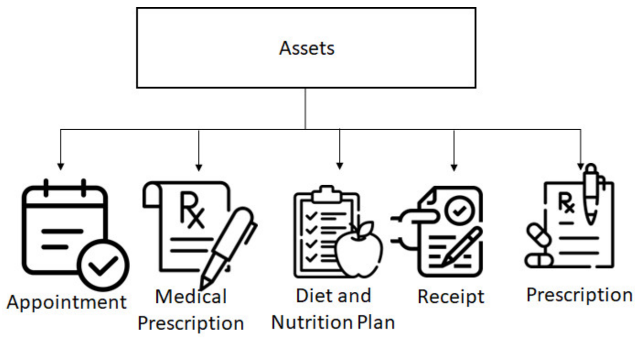

Figure 3. Assets Module.

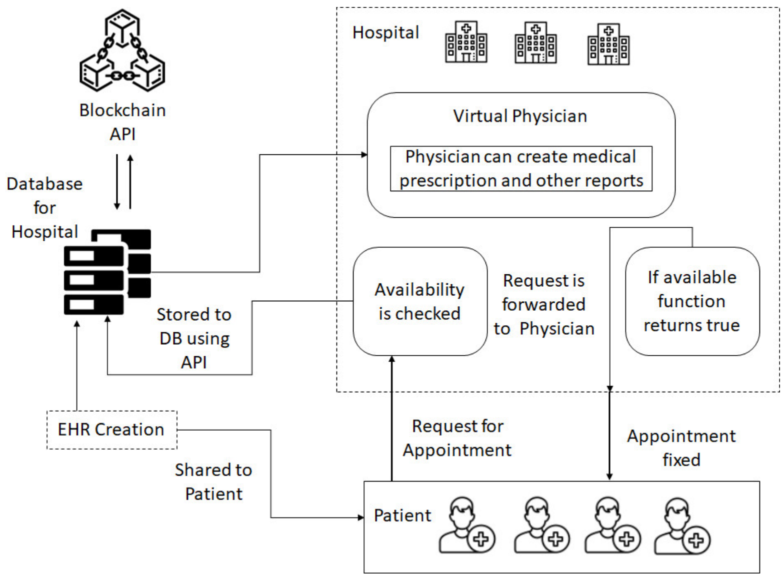

Figure 4. Virtual Physician–Patient Appointment Module.

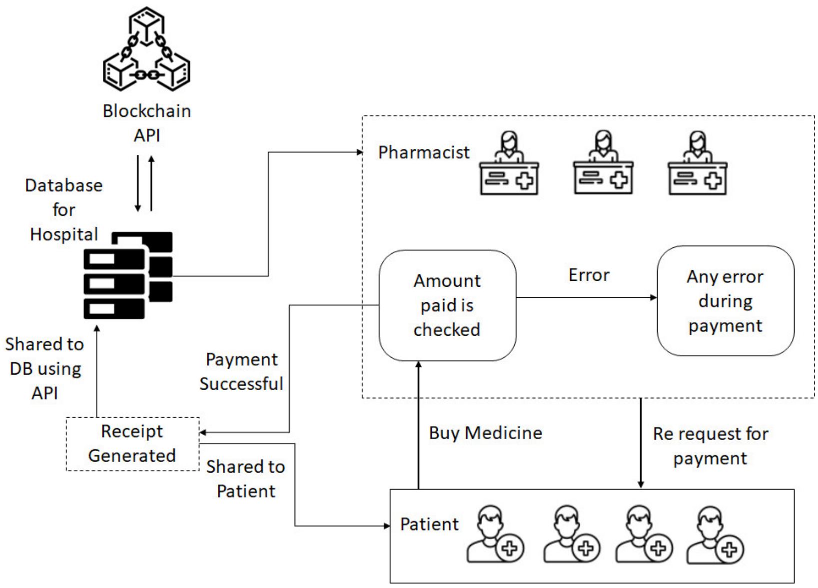

Figure 5. Pharmacist–Patient Interaction Module.

3.1. System Architecture

This research work primarily is concerned with the COVID patient's EHR management based on the blockchain framework, which defines participants, assets, transactions, and smart contracts to trace functionality. To arrange an appointment, the patient must first register via the client interface using a chain code. Distributing the transaction over the network notifies all stakeholders of the committed transaction (appointment), ensuring data security and robustness against unauthorized attackers. This transaction has a timestamp and hash value in the distributed ledger, making it easy to verify the patient's identity. Using the blockchain-enabled communication network, all authorized parties can access and inquire about this healthcare data. Patients can ask the physician about their appointments, medications, reports, clinical diagnoses, diet charts, and other issues.

3.2. Transactions, Participants, and Related Assets in the Proposed Research Work

The Hyperledger Composer has a strong collection of open-source tools that certainly enable the development of blockchain applications and smart contracts while enhancing operational efficiencies. Hyperledger Composer facilitates the construction and configuration of the blockchain's key components, such as the transaction logic, assets, access control, and participants. It also defines the blockchain transaction processing business rules, the assets exchanged in different use cases, and participant control, roles, identities, and levels of access for executing different transactions. Composer enables component sharing, reusability, and scalability across several organizations. A complete case study was produced for the planned healthcare system, which aids in the identification of the participants and assets that will be necessary for the development of the application. The transaction definition also specifies the transactions that must be completed in order to carry out a specific feature.

(1) **Participants:** Participants represent an individual or group of individuals or organizations. A member who is present in the network has the ability to create assets as well as to exchange assets with the other network participants. Figure 2 shows a list of the participants who have already signed up for our application.
(2) **Assets:** Assets are any tangible or intangible things that can be used to generate income. To give an example, a receipt is a physical object. Transactions, which are different from one another, can be used to modify these assets. Figure 3 depicts a list of all of the assets associated with our application.
(3) **Transactions:** Whenever the request for reading and writing from the ledger is made, a transaction is initiated, which further initializes the chain code on a channel. Through the endorsement of peers, application clients can collect, invoke, or instantiate replies. Furthermore, the clients can encapsulate the endorsed results in a transaction, which will then be submitted for committing, validating, and ordering.

As previously mentioned, a virtual physician is available. Figure 4 depicts the primary transaction generated to confirm the appointment. A patient with COVID-19 is seeking an appointment under a specific symptom category. To arrange an appointment, the appropriate category of available virtual physicians is selected.

In the second transaction, a patient purchases drugs from a pharmacy. A pharmacist requires that a specific sum be paid, and if the patient is successful in paying the requested amount, a receipt is issued as depicted in Figure 5.

In the third transaction, a patient purchases a lab test from a pathology lab. A pathologist requires that a specific sum be paid, and if the patient is successful in paying the requested amount, a receipt is issued as depicted in Figure 6. Similarly, Figure 7 depicts the fourth transaction, to confirm the appointment with a dietician.

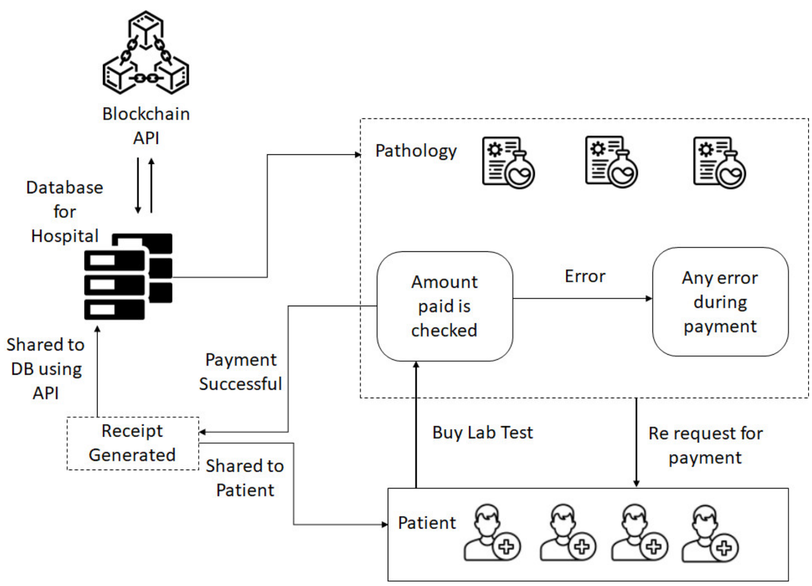

Figure 6. Pathology–Patient Interaction Module.

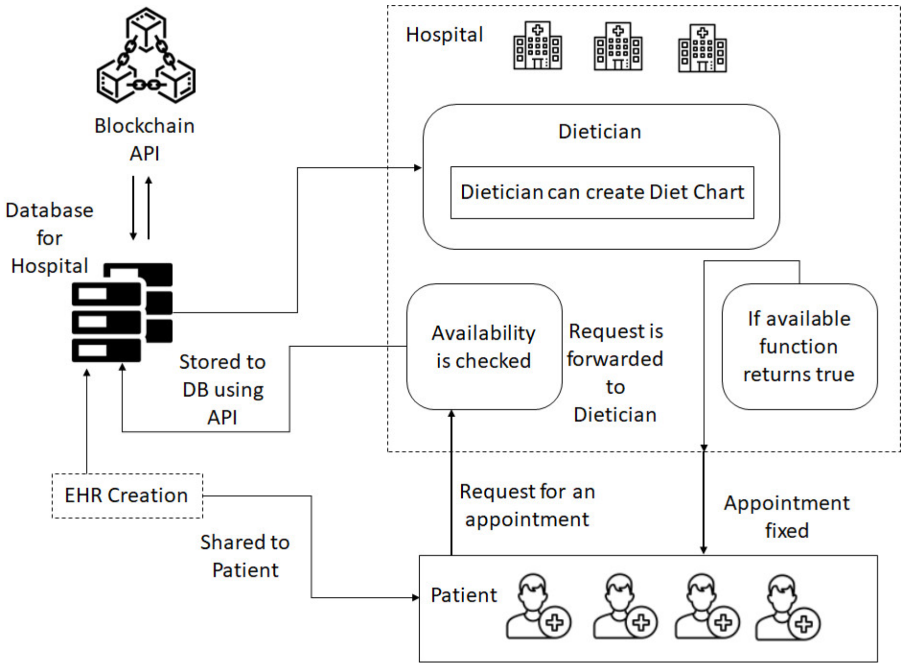

Figure 7. Dietician–Patient Interaction Module.

3.3. Interaction among the Participants

In the proposed framework, the virtual physician, pharmacist, pathologist, patient, and dietician are included as participants, and the appointment, med prescription, diet plan, receipt, and prescription are represented as assets. V, H, T, P, and D represent the IDs for the virtual physician, pharmacist, pathology, patient, and dietitian, utilizing blockchain and saved to the database of the hospital. The following describes how participants interact with each other:

3.3.1. Virtual Physician and Patient Appointment

In this section, a patient submits a request for an appointment with a virtual physician. The following are some of the functions that the module provides:

k = Set of symptoms that can be treated

P = Set of Patients

V = Set of virtual physicians available

A = Set of Appointment IDs

PIDi = Identification of i^{th} patient where $i \in (1, P)$

VIDj = Virtual Physician ID of virtual physician j, where $j \in (1, V)$

AIDi = Appointment identification of i^{th} patient, which is assigned to virtual physician *j*.

ki = Individual symptom *i*, where *i* can range from 1 to n symptoms from set of symptoms, k

Spir = Patient *i* is suffering from symptom r.

The following equation demonstrates the objective functions: R = X + Y

$$X = \begin{cases} 1 & if\ SPir = ki \\ 0, & otherwise \end{cases} \tag{1}$$

Patient *i* is suffering from symptom r is equal to particular symptom *i* from set of symptom k

$$Y = \begin{cases} 1 & if\ AIDij = A \\ 0, & otherwise \end{cases} \tag{2}$$

The appointment can be considered as confirmed when the value of R = 1.

3.3.2. Virtual Physician Consultation

In this module, predefined constraints, such as a patient's appointment confirmation status booked or pending and fee charged for the appointment made, are used to confine the execution of this module functions. The following equation demonstrates the objective function of the virtual physician consultation.

$$\mathrm{R} = \begin{cases} 1 \quad if\ ASi = \text{“}CONFIRMED\text{”} \\ 0, \quad otherwise \end{cases} \tag{3}$$

Here, A represents the set of appointment IDs
Asi = i^{th} patient's appointment status
R must be 1 for booking a virtual physician consultation.

3.3.3. Pathology and Interaction among Patients

This segment consists of various sub-modules, namely, a pathology test, patient, and virtual physician. The group of tests by pathology test IDs is marked by T. The amount of the transaction, IDs of the virtual physician and patient are defined in the equation given below:
PID = ID of ith patient, where $\boldsymbol{i} \in (\mathbf{1}, \boldsymbol{P})$
GIDi = ith pathology_test ID, where $\boldsymbol{i} \in (\mathbf{1}, \boldsymbol{G})$
Ai = Amount requested by pathology to test reports
Ti = Total amount deposited.
The following equation demonstrates the objective function of the pathology–patient interaction

$$\mathrm{RP} = \begin{cases} \mathbf{1} \quad \boldsymbol{if\ Ai \leq Ti} \\ \mathbf{0}, \quad \boldsymbol{otherwise} \end{cases} \tag{4}$$

Here RP represents the probability of receipt generation.

3.3.4. Pharmacist and Patient Interaction

This module consists of pharmacist, patient, and a virtual physician. The pharmacist will use blockchain technology to maintain the record of medicines that a patient has purchased and issue a receipt for that. The functionality of this module is defined as:
H = existing pharmacists set
P = Patients set
HIDi = ith pharmacist ID, where $\boldsymbol{i} \in (\mathbf{1}, \boldsymbol{H})$
PIDi = ith patient ID, where $\boldsymbol{i} \in (\mathbf{1}, \boldsymbol{P})$
Ti = Total amount deposited
Ai = Amount requested by a pharmacist for prescribed medicine.
Here, the pharmacist–patient functionality is demonstrated by the following equation:

$$\mathrm{RP} = \begin{cases} \mathbf{1} \quad \boldsymbol{if\ Ai \leq Ti} \\ \mathbf{0}, \quad \boldsymbol{otherwise} \end{cases} \tag{5}$$

where RP must be 1 for receipt generation.

3.3.5. Dietician and Patient Interaction

Two sub-modules, such as patient and dietitian, comprise this module, indicated by the symbols P and D, and the IDs of the patient and dietician are saved using blockchain in the database of hospital. A patient makes an appointment request in this module. The functions used in this module are defined as under:

A, D and P represent the set of appointment IDs, available dieticians, and patient IDs, respectively.

DIDj = dietician identification of dietician j where j $\in (\mathbf{1}, \boldsymbol{D})$

PIDj = ith patient ID, where i$\in (\mathbf{1}, \boldsymbol{P})$

AID_{ij} = appointment identification of ith patient assigned to jth dietician.

The following equation demonstrates the objective function of the dietician and patient interaction:

$$S = \begin{cases} \mathbf{1} \quad \boldsymbol{if\, ASi} = \text{“}\boldsymbol{CONFIRMED}\text{”} \\ \\ \mathbf{0}, \quad \boldsymbol{otherwise} \end{cases} \tag{6}$$

$$R = \begin{cases} \mathbf{1} \quad \boldsymbol{Ai} \leq= \boldsymbol{Ti} \\ \\ \mathbf{0}, \quad \boldsymbol{otherwise} \end{cases} \tag{7}$$

4. Implementation

The implementation section of this paper focuses on the practical aspects of deploying the Hyperledger Fabric-based blockchain-enabled COVID-19 patient-centric architectural framework. In this section, we provide a detailed account of the steps taken to implement the proposed solution, including the setup of the blockchain network, the design and development of smart contracts, and the integration of necessary components. By outlining the implementation process, we aim to provide a clear understanding of the technical aspects involved and offer insights into the practical feasibility of the framework. This section serves as a guide for researchers, developers, and healthcare professionals interested in implementing similar blockchain solutions for healthcare management during public health emergencies.

4.1. Deployment Phase

Hyperledger is an open-source initiative designed to facilitate the development of distributed ledgers based on blockchain technology. The proposed architectural framework was designed using Hyperledger fabric. Hyperledger is a collaborative effort to provide the frameworks, protocols, tools, and libraries required to construct blockchains and related applications. The Hyperledger Sandbox is an environment for testing the performance of Hyperledger projects and enhancing the performance of blockchain platforms. Sandbox is ideal for understanding the concepts of participants, assets, transactions, and events. Go, Java, and Node.js are used to create smart contracts. The proposed architectural framework comprises the subsequent phases:

1. The first phase of network implementation includes designing participants and assets. Business network creation allows application coding. After application coding, the authors created a.bna file (banana file). Hyperledger’s online playground was used to test this file.
2. In the second phase, the appointment, buying medicine, pathology test, dietician, and physician’s diagnosis are tested with the framework.
3. In the third phase, the patient and virtual physician confirmed appointments as a module in the framework. Testing1 creates a participant patient. The authors also developed an asset appointment for participants. Testing 2 creates the asset. Testing 3 shows an appointment transaction between the patient and the virtual physician IDs.

When the transaction is completed, the status of the appointment register is updated, and it reflects the status conformation from pending to confirmed, as depicted in Testing 4. The proposed framework includes a pharmacist module. This module is checked by buying drugs as shown in Testing 5. Testing 6 shows the receipt after a successful purchase.

Testing 1: Creation of Participant


```
{
  "$class": "covid.org.ehr.basic.Patient",
  "debt": 0,
  "Symptom": "Fever",
  "id": "4001",
  "firstName": "Sabita",
  "lastName": "Khatri"
}
```


Testing 2: Creation of Asset


```
{
  "$class": "covid.org.ehr.basic.Appointment",
  "appointmentId": "6001",
  "status": "PENDING",
  "isInsured": false,
  "description": "come on time",
}
```


Testing 3: Creation of Transaction


```
{
  "$class":
"covid.org.ehr.basic.confirmAppoint",
  "patient":
"resource:org.ehr.basic.Patient#4001",
  "virtualphysician":
"resource:org.ehr.basic.Virtual Physician#5001",
  "appoint":
"resource:org.ehr.basic.Appointment#6001"
}
```


Testing 4: Asset Updation


```
{
  "$class": "covid.org.ehr.basic.Appointment",
  "appointmentId": "6001",
  "status": "Confirmed",
  "description": "come on time",
}
```


Testing 5: Transaction execution


```
{
  "$class": "covid.org.ehr.basic.buyMed",
  "patient":
"resource:org.ehr.basic.Patient#4001",
  "chemist":
"resource:org.ehr.basic.Chemist#7001"
}
```


Testing 6: Asset Generation


```
{
  "$class": "covid.org.ehr.basic.Receipt",
  "receiptId": "R001",
  "providerId": "5001",
  "providedTo": "4001",
  "amountPaid": 5000,
  "logtime": "2022-05-15T05:15:01.8811" "
}
```


The precise execution of admin in a blockchain network is shown in Algorithm 1 and systematic execution among participants is defined in Algorithm 2 respectively.

Algorithm 1: Enrollment of Participant and Admin.

Input: Registration Certificate (RC) request from certificate authority (CA)
Output: Transaction Access to ∀ (V, P, H, T, I) ∈ BN
Initialization: Nadmin node = valid
Nadmin Permissions are (Read, Write, Update, Removal) of V, P, H, T, I

Procedure ADMIN (V, P, H, T, I)

```
While (true) do
   if Vid found valid then BN
      Add_V to BN
      Add_V (BN, Vid);
      Grant_access (Vid);
   Else
      Not_exist (VN)
   End
   If PID found valid then
      Add_P to BN
      Add_P (BN, PID);
      Grant_access (PID);
```

Algorithm 1: *Cont.*

```
    Else
       Not_exist(PID);
    End
    If HID = found valid then
       Add_H to BN
       Add_H(BN, HID);
       Grant_access(HID);
    Else
       Not_exist(HID);
    End
    If TID = found valid then
       Add_T to BN
       Add_T(BN, TID);
       Grant_access(TID);
    Else
       Not_exist(TID);
    End
    If IID = found valid then
       Add_I to BN
       Add_I (BN, TID)
       Grant_access (IID);
    Else
       Not_exist (IID);
    End
 End
 Int N: (found malicious 1 not malicious 0)
 For all (*) do
    If (node found malicious) then
    Not update (VID, PID, HID, TID, IID)
    Else
       Update (VID, PID, HID, TID, IID)
    End
 End For
End Procedure
```

Algorithm 2: Working of Participant, fixing of appointment, buying medicine and lab record, dietician consultation.

Input: initiate request from N admin for keys & IDS
Output: get access to transaction
Initialization: VN, PN, HN, TN, IN should be valid node

Procedure Appointment (AID)

```
While (true) do
   If (PN ∈ BN) then
       If PID = not in BN then
      Create record (PID, PREC, BN);
      Else
      Read records (PID, PREC, BN);
      Update records (PID, PREC, BN);
      End
   Else
      Not_valid (PID)
   End
   If VN ∈ BN then
```

Algorithm 2: *Cont.*

```
        If VID not in BN then
        Create records (VID, VREC, BN);
        Else
        Read_records (VID, VREC, BN);
        Update_records (VID, VREC, BN);
        End
    Else
        Not_valid(VID)
    End
    If HN ∈ BN then
        If HID not in BN then
        Create records (HID, HREC, BN);
        Else
        Read records (HID, HREC, BN);
        Update_records (HID, HREC, BN);
        End
    Else
        Not_valid(HID)
    End
    If TN ∈ BN then
        If TID not in BN then
        Create records (TID, TREC, BN);
        Else
        Read records (TID, TREC, BN);
        Update records (TID, TREC, BN);
        End
    Else
        Not valid(TID)
    End
    If DN ∈ BN then
        If DID not in BN then
        Create records (DID, DREC, BN);
        Else
        Read_records (DID, DREC, BN);
        Update_records (DID, DREC, BN);
        End
    Else
        Not_exist(DID);
    End
End
N = 0 (participant non availability) 0 or 1 (participants availablilty);
If (Appointment (VID, PID)) then
MPID = Drug Record (PID, VID);
         If N = 1 then
        Generate permission for record (MPID)
        Reciept_Generation (PID, VID);
        Else
        Notify ("Error");
        End
Else
End
Int N: 0 (payment status invalid) or 1 (payment status valid);
If (purchase drugs (HID, PID) then
        If N = 1 then
        Generate permission for record (MPID)
        Receipt Generate (PID, HID);
        Else
        Display ("Found Error");
```

Algorithm 2: *Cont.*

```
        End
Else
    End
Int N: 0 (participant's non availability) or 1 (participants' availability);
If (Appointment (VID, PID) then
        LID = Lab Record (PID, VID);
        If N then
        Grant records (LPID)
        Else
        Display ("Error Found");
        End
Else
    End
Int N: 0 (payment status false) or 1 (payment status true);
If (purchase testing (PID, TID) then
        LID = Lab record (PID, TID);
        If N then
        Grant permission for records (LID)
        Receipt Generation (PID, VID);
        Else
        Display ("Error found");
        End
Else
End
Int N: 0 (participants availability false) or 1: (participants availability true);
If (Appointment (IID, PID) then
        CID = dietician (IID, VID);
        If N then
        Grant permission for records (CID)
        Receipt Generation (PID, IID);
        Else
        Display ("Error found");
        End
Else
End
Int N: 0 (payment status false) or 1: (payment status true);
If (taking consultation (IID, PID) then
        CID = Diet Chart (PID, IID);
        If N then
        Grant Chart (CID)
        Generate receipt (PID, IID);
        Else
        Notify ("Error");
        End
Else
End Procedure
```

4.2. REST Server Implementation

Using the REST server, a business blockchain network can be used to make a Representational State Transfer Application Programming Interface (REST API). From the Fabric blockchain, a REST client can call these endpoint functions to interact with a business-based application network that has been deployed. The interface is compatible with both client and Hypertext Transfer Protocol (HTTP). Users create, read, update, and delete (CRUD) via an API and REST, which uses the HTTP protocol's request types such as POST, GET, PUT, and DELETE. In this, stakeholders are allowed to receive responses from the other authorized stakeholders after raising a query. The REST server response is used to read the patient's records and for performing GET, POST, DELETE participants.

5. Performance Analysis of Proposed Solution and Findings

The assessment focused on critical characteristics such as endorsement policy, block size, and production time, all of which have a substantial impact on the system's efficiency and effectiveness. We used a methodical methodology that addressed domain-specific criteria and used meetings with domain experts as well as stakeholders to guarantee transparency and robustness in our research. The endorsement policy for the proposed solution has been chosen based on the specific requirements for the COVID-19 patient-centric use case. Authors held extensive consultations with healthcare professionals, government officials, and other stakeholders to learn about their preferences and trust needs for data exchange and validation. Authors chose a combination of endorsement policies according to their suggestions to ensure an excellent level of data integrity while supporting the need for involvement and consensus among authorized organizations. The block size has a significant impact on the blockchain network's performance and scalability. To determine the best block size, Authors undertook a series of experiments with various block sizes ranging from small to huge.

The authors have conducted a comprehensive analysis of critical performance metrics, such as throughput, memory, and CPU utilization, to assess the influence of block size on transaction efficiency for data storage and processing. The research also focused on exploring the connection between blockchain transactions and system resources, specifically tailored to meet the requirements of a COVID-19 patient-centric use case and its corresponding architecture. During their investigation, the authors evaluated various time intervals to determine the optimal pace of transactions between organizations. The results of this performance analysis highlighted the effectiveness of the proposed approach, showcasing standard transaction operations, and demonstrating satisfactory querying and writing performance at the desired levels. These findings underscore the suitability and viability of the proposed solution for handling the COVID 19 use case.

The proposed framework's performance was evaluated by the authors. Experimentation, latency, throughput, and other crucial characteristics were calculated while considering variables such as endorsement policy, block size, and creation time, etc. The performance of the applications created on the Hyperledger platform over the network was measured for evaluation using the Hyperledger Caliper tool. By utilizing this tool, several characteristics such as memory consumption, CPU utilization, throughput, latency, traffic coming into and going out of the system, network I/O, disc write/read speeds, and soon were evaluated. The evaluation served as the basis for adjusting the configuration parameters, which included changes such as resource utilization, block size, transactions per second, channel, support method, and record database. In order to conduct a performance analysis, the suggested model was tested by using standard transaction operations such as writing and querying. Within the context of a blockchain, a query transaction is noticeably more expedient than a write transaction. It was observed that the latency increased with both the size of the operation and the transaction rate. When considering the higher throughput, Equation (8) demonstrates how the lower latency can be linked to the higher throughput.

$$\text{TL} = (\text{CT} * \text{NT}) - \text{ST} \tag{8}$$

$$\text{TT} = (\text{TCT}/\text{TTS}) - \text{NCN} \tag{9}$$

$$\text{RL} = \text{RR} - \text{ST} \tag{10}$$

$$\text{RT} = \text{RO} - \text{TT} \tag{11}$$

Here TL, CT, NT, ST, TT, RL, and WL represent the transaction latency, confirmation time, network threshold, submit time for transaction, transaction throughput, read latency, and write latency, respectively. For establishing the efficacy of the proposed model, the authors conducted the experiment using 1000 transitions in a ledger for the first round over three rounds of transactions executed three times, including both query and write transactions. An organization can participate in the Hyperledger Fabric network only if it has been granted authorization by the network's administrators. Members are a term used to describe the organizations. In the blockchain network, each participant has the option of establishing their own peers. A peer can participate in the network as a participant. Each organization has the option of configuring the entire network to have a single participant or multiple members represent the organization as a whole. In this proposed framework two organizations and one peer of a network were taken into consideration. 1org1peer represents a single peer of the 1org network in a network. Furthermore, 2org1peer specifies the chain code that runs on both organization peers, changing throughput and latency performance. The transaction was executed and created by EHR chain code. Before committing, peers endorse and broadcast the transactions. Numerous parameters, including average memory, CPU utilization, disc read/write, incoming and outgoing traffic, etc., were taken into account when performing Caliper testing for the network. The average CPU consumption is depicted in Figure 8; numerous peers can be seen in this context. It shows the average CPU % utilization against transactions per second (TPS). It indicated that the CPU utilization of peer0.org1 was higher than peer0.org2. Figures 9 and 10 depict the memory utilization against TPS and transaction rate against the throughput, respectively.

Figure 10 defines transaction rate to throughput. 1org1peer's throughput was 190, whereas 2org1peer's was low (177). Figure 11 shows the time needed for each transaction round. 1org1peer completed 2000 transactions in 130 s while 2org1peer completed 1000. The transaction time grew with organization and peer growth. In Figure 12, block size 10 produces higher spikes, or more transactions per second, compared to block size 20, which produces fewer transactions. In Figures 13 and 14, when compared to writing a transaction, it was observed that reading or querying was substantially faster.

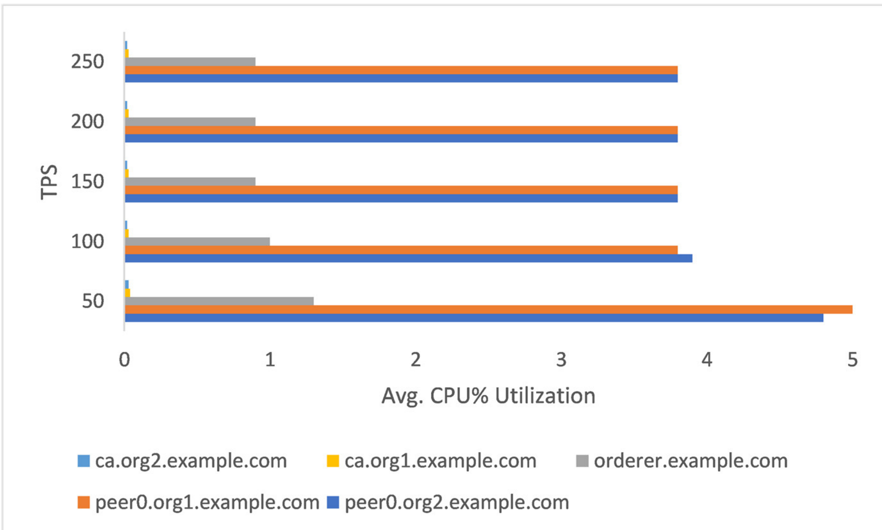

Figure 8. CPU utilization against TPS.

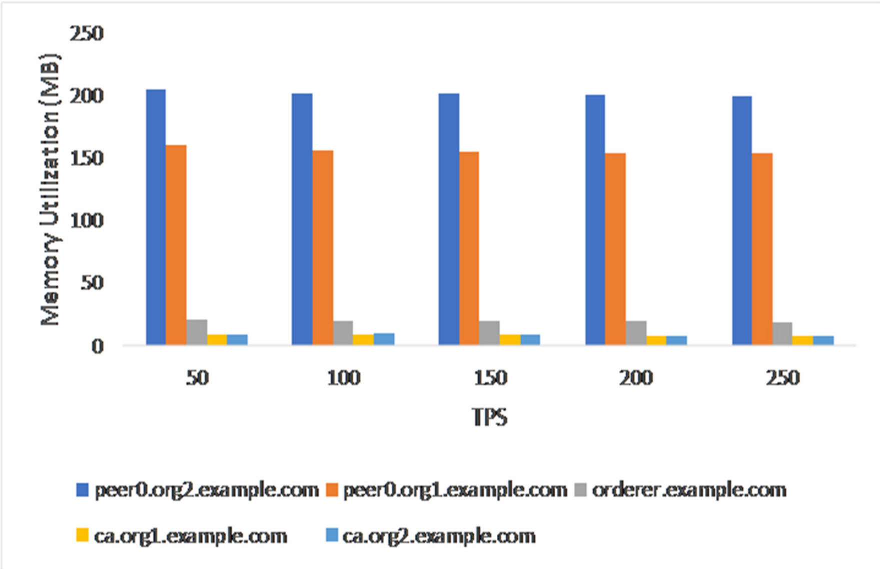

Figure 9. Memory Utilization against TPS.

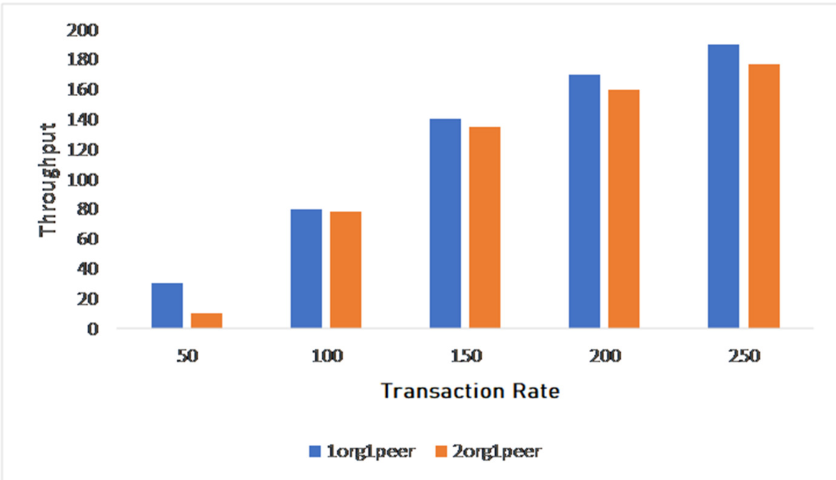

Figure 10. Transaction Rate against Throughput.

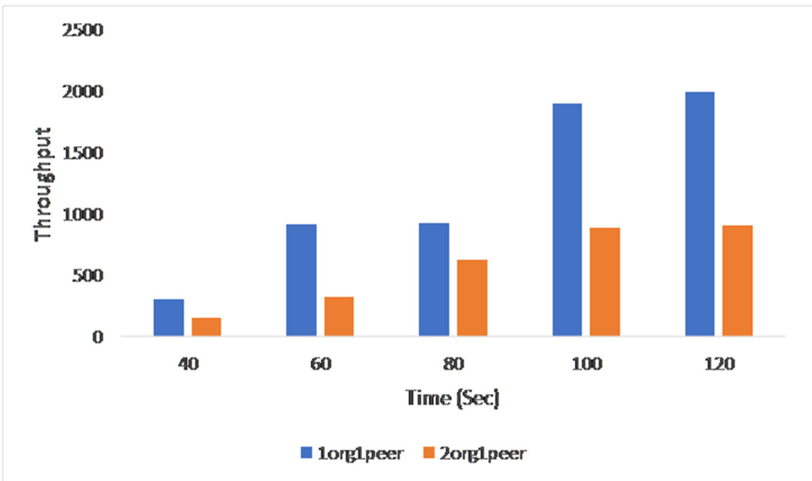

Figure 11. Transactions by time.

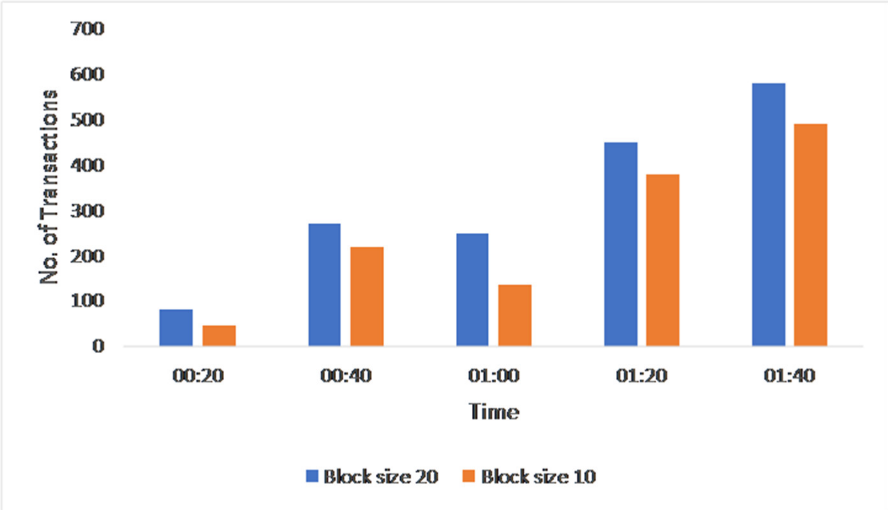

Figure 12. The interaction of block size and transactions.

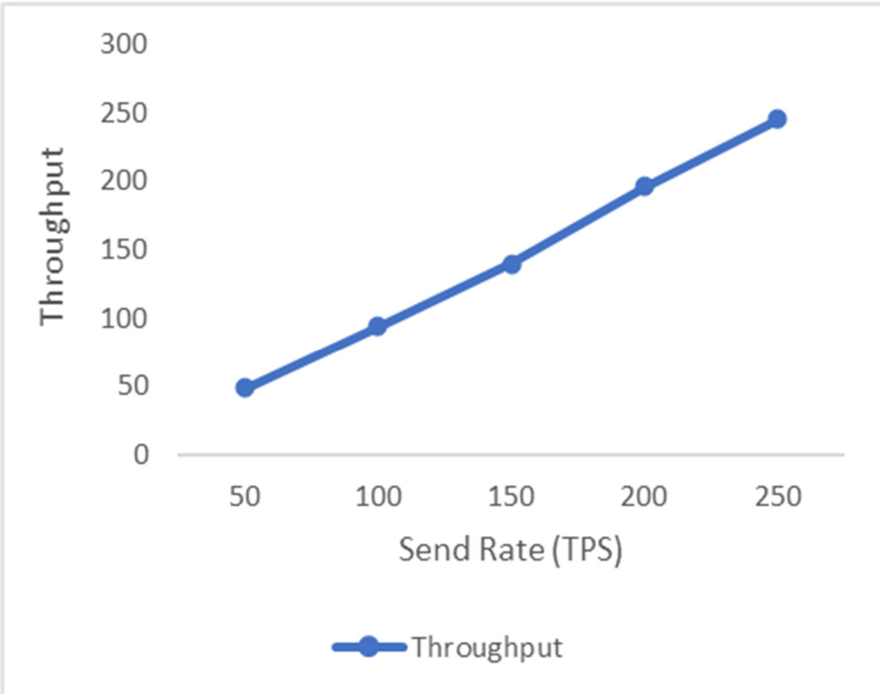

Figure 13. Throughput for reading.

Thus, the performance analysis indicated that our suggested solution adequately fit the expectations of the COVID-19 patient-centric use case, with carefully set endorsement policies, block size, and generation time. It achieved a healthy combination of data integrity, efficiency, as well as real-time access to healthcare data. The transparency and rigorous approach we took in examining these variables strengthened the robustness of our findings and contributed to the dependability and efficacy of our blockchain-enabled solution.

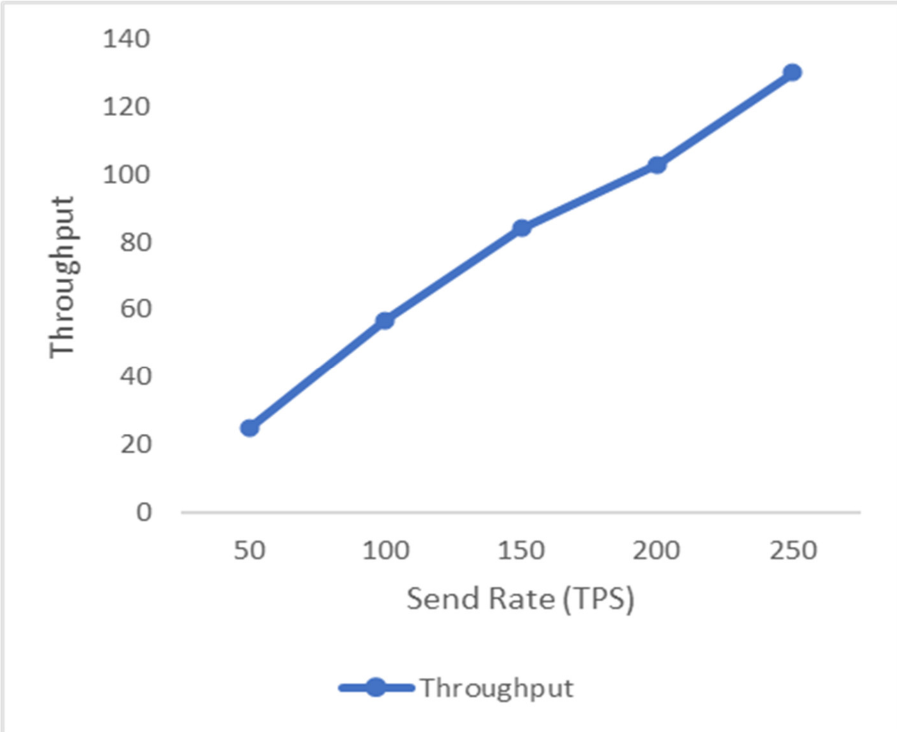

Figure 14. Throughput for writing.

6. Discussion

The proposed Hyperledger Fabric-based blockchain-enabled COVID-19 patient-centric architecture framework provides numerous advantages and applications. To begin with, the inclusion of blockchain technology in the system provides the confidentiality and immutability of healthcare data, reducing the danger of data manipulation and increasing confidence among medical practitioners and patients. The framework facilitates informed decision making by authorities as well as helps in the creation of effective public health guidelines by facilitating accurate information collection from COVID-19 patients. Furthermore, the patient-centric design increases healthcare accessibility as well as EHR management, resulting in personalized and efficient medical care. The framework's ability to manage a high number of transactions while maintaining low latencies makes it ideal for dealing with crucial situations during public health emergencies. In general, the planned effort has the potential to revolutionize healthcare management, improve data security, and encourage trust in medical institutions.

The research findings demonstrated that the use of Hyperledger Fabric in the implementation of the framework offers significant benefits in terms of the security, authenticity, and privacy of health records. Through the application of JavaScript-based smart contracts, the system ensures trust between medical professionals and patients while mitigating the risk of accidental coronavirus transmission. The adoption of Hyperledger Caliper as a benchmarking tool allows for the evaluation of the framework's performance and resource utilization under various scenarios and control parameters. The results of the performance analysis highlighted the scalability and efficiency of the proposed framework. Notably, the transition from a 1org1peer to a 2org2peer network resulted in an increased maximum throughput of 190 transactions per second (TPS). Furthermore, doubling the block size demonstrated a tenfold increase in TPS, indicating the system's ability to handle a higher volume of transactions. The discussion also emphasized the broader implications of blockchain technology in the healthcare domain. By addressing issues such as authentication, immutability, and privacy, blockchain has the potential to revolutionize healthcare data management. It enhances data access, interconnection, accountability, and authentication, offering a decentralized approach to data protection in healthcare [34–39].

Despite these promising findings, it is important to acknowledge the limitations of the study. The research focused specifically on the COVID-19 pandemic and the associated challenges in healthcare management. However, further investigation is needed to explore the applicability of the proposed framework to other public health emergencies or healthcare scenarios. Adoption is a serious task, especially within the healthcare sector. Implementing a new technology such as blockchain necessitates considerable modifications to existing systems as well as processes, which may face opposition from healthcare organizations and specialists. The adoption procedure could be time-consuming as well as resource-intensive, potentially resulting in implementation delays. Furthermore, regulatory obstacles must be carefully addressed. Healthcare data is extremely sensitive, and rigorous restrictions are in place to protect patient privacy and data security. Current healthcare regulations, including the HIPAA (Health Insurance Portability and Accountability Act) in the United States as well as the GDPR (General Data Protection Regulation) in the European Union, should be thoroughly evaluated and incorporated into the proposed framework. Failure to comply with these regulations may result in legal complications and impede the system's deployment. Interoperability with existing healthcare infrastructure may also be an issue. Many healthcare organizations already have electronic health record systems in place, and incorporating the proposed blockchain solution into these systems may necessitate significant technological tweaks and extensive testing to ensure seamless data flow and compatibility. Additionally, while the performance analysis showcased the effectiveness of the framework, additional research is required to evaluate its long-term scalability, adoption challenges, and potential impact on existing healthcare systems.

7. Conclusions

In order to address issues such as authentication, immutability, and privacy, this research provided a blockchain-enabled healthcare system based on a patient-centric design for COVID-19. The design includes a thorough strategy for implementation and operation as well as a performance analysis. Hyperledger was used for the implementation. Hyperledger Caliper was used to assess the model's performance and resource usage. It was found that the average write latencies exceeded the read counterparts. It was observed while shifting from a 1org1peer to a 2org2peer network; the maximum throughput was scaled to 190 TPS with a 13 TPS loss. With a twofold increase in block size, the tenfold increase in TPS was observed. The authors found that blockchain is crucial in dealing with deception in clinical trials; the potential of this technology here is to improve the access to healthcare data while securing the integrity of the data. It can help to alleviate the fear of data manipulation in healthcare by enabling a one-of-a-kind data storage pattern with the highest level of security. It offers data access versatility, interconnection, accountability, and authentication. Health records must be kept secure and confidential for a variety of reasons. Blockchain contributes to the decentralized protection of data in healthcare, assists in avoiding certain threats, and has the ability to deal with a situation similar to the COVID-19 pandemic.

Looking ahead, future research in this field can explore several promising directions. First, the scalability and performance of the proposed blockchain-enabled healthcare system can be further examined and optimized to handle larger networks and accommodate diverse healthcare scenarios. Additionally, studies can focus on integrating advanced data analytics and machine learning techniques into the system to derive valuable insights and support informed decision making. Furthermore, efforts can be made to evaluate the feasibility and potential benefits of implementing the proposed framework beyond the context of COVID-19, encompassing other public health emergencies and healthcare domains. Exploring the interoperability of blockchain systems and ensuring compatibility with existing healthcare infrastructure are also areas that warrant further investigation.

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