Research Article / Review Article FUPRE JOURNAL 8(3):160-174(2024)

FUPRE Journal

of

Scientific and Industrial Research

ISSN: 2579-1184(Print) ISSN: 2578-1129 (Online)

http://fupre.edu.ng/journal

Deployment of a Secure Electronic Health Information Management System

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ARTICLE INFO

Received: 09/12/2023

Accepted: 13/04/2024

Keywords

Arduino,
Embedded systems,
Node MCU,
Raspberry Pi,
Virtual key-card.

ABSTRACT

The adoption of blockchains to effectively manage medical services – is fast become popular, for professional use and in patient-centered application. Electronic medical records are highly sensitive with user-privacy data in lien with medical-related services for patient diagnosis and treatments. The nature and features of these medical records have continued to necessitate its availability, reachability, accessibility, mobility, confidentiality and security. These, have been demystified with the birth of the blockchain technology that seeks to proffer platforms and application services devoted to dependability, reliability amongst the features earlier mentioned above. Thus, our study posits a blockchain health information system for healthcare facilities in Delta State of Nigeria. Our ensemble yields a permissioned blockchain using a hyper-fabric ledger. Using the world-state on a peer-to-peer blockchain with various actors to include patient, practitioners and other users to create, retrieve and store medical records for a patient to aid interoperability – our ensemble yields a query and https response time of 0.56secs and 0.42secs respectively for 2500-users, and 0.78secs and 063secs respectively for 7500-users.

1. INTRODUCTION

Electronic medical records (EMR) have revolutionised the format of health records, transformed the healthcare industry and made patients' medical records easier to access anywhere (Abu-elezz et al., 2020; Aghware et al., 2023a; Allenotor & Ojugo, 2017; Dang et al., 2019). However, all the records in the conventional storage approach can be manipulated or altered easily, which creates concerns in terms of security and privacy of patients (Aghware et al., 2023b; Allenotor et al., 2015). The healthcare ecosystem is quite complex, with multiple stakeholders and actors involved in complex and sensitive data interactions (Gier et al., 1978; Habib et al., 2022). This can lead to privacy challenges, data insecurity, and operational inefficiencies. Ownership and trusted access to medical data is a critical process that must be made simpler, fast, and cost-effective (Akazue et al., 2022; Eboka & Ojugo, 2020; Oyemade et al., 2016). EMRs are electronically-stored, highly sensitive and private information that details diagnosis and treatment of patient, and needs to be frequently shared among peers. Sharing of medical records between participants is very challenging because the data might be revealed or tampered during the operational process (Arias-Oliva et al., 2019; Avinadav, 2020; Ojugo, Akazue, Ejeh, Ashioba, et al., 2023; Ojugo, Akazue, Ejeh, Odiakaose, et al., 2023). Automating EMR has as its focal goal, the issue of referrals to medical practitioners

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in other facilities – where records are easily available to them and therein, to cooperate with participatory health, providing some semblance of partnership with digital devices collecting data and generating insights, adopt new models of care, evolve via collaborations between clinicians and patients. Protecting the privacy of medical records is a mandatory (Hassan et al., 2019; Hossain Faruk et al., 2021; Ojugo et al., 2015; Ojugo, Abere, Orhionkpaiyo, Yoro, et al., 2013).

Advances in informatics has brought about useful contribution in healthcare; even though it has its issues. Current healthcare systems are health providers centric with low interoperability. Patients are not bound to a specific hospital or doctor (Khatoon, 2020; H. M. Kim & Laskowski, 2018; Okobah & Ojugo, 2018). They may visit a doctor, or be referred from a clinic, for which case, sharing patient's medical data for better treatment is mandatory. EMRs of a medical facility is not always available to another facility, and the issue of care coordination across healthcare (J. W. Kim et al., 2022; Lewis, 2015). Also, patients have no control of their medical data; And in some instance, are tempered with, stolen, or shared without their consent (Kokoris-Kogias et al., 2018; Ojugo & Eboka, 2014, 2018, 2019a, 2019b).

A challenge in medical data exchange is interoperability (Li et al., 2022). Many health systems use databases in proprietary formats. These databases are structured to be accessed exclusively by those systems, with little or no interoperability with others (Liu et al., 2020). At every appointment, patients must tell their whole health history again, losing time and accuracy. Also, there are technical issues with health records, due to standards for different purposes (Ojugo, Odiakaose, et al., 2023; Ojugo, Ugboh, Onochie, Eboka, et al., 2013).

1.1 Blockchain Technology

Blockchain emerged as a novel approach to run cryptocurrency; Though, it portends a variety of solution advocated by industries such as healthcare to enhance authentication, confidentiality, transparency, and unique data sharing feat, and verified by consensus mode (Yoro, Aghware, Akazue, et al., 2023; Yoro, Aghware, Malasowe, et al., 2023). Its ability to address healthcare issues, also allows it to leverage on emerging techs (Mamun et al., 2022; Mao et al., 2018; Murthy et al., 2020; Ojugo & Eboka, 2019c). Despite the issues of interoperability, there is the lack of standards for developing healthcare apps. Blockchain can solve the problems in today's healthcare industry (Ojugo et al., 2012; Ojugo, Ejeh, et al., 2023).

Blockchain is a complex data structure in which growing records are stored in blocks. Its 4-basic elements are data, current block hash, previous block hash, and timestamp. So, if we add new data blocks to the blockchain, each new block is linked to the previous one. using a hash value which makes it immutable, and all the workflow is recorded are time-stamped which places an identity to it and the replicas are distributed to each network node that is a participant, this guarantees that the data integrity is kept between the endpoints without any human involvement (Naz & Lee, 2020; Nazir et al., 2017; Nishi et al., 2022).

A blockchain is a distributed transaction ledger (Onik et al., 2019). It is a distributed database in which a linear collection of data elements called blocks are linked together to form a chain, and secured by cryptographic primitive (Ojugo et al., 2021b, 2021a). It is a record-keeping mode that uses decentralised distributed database. The list of records is kept in a block, which is linked together to form a chain. Hacking a blockchain is tough because if one block is hacked, the attacker must hack every block because each block's hash pointer is linked to the next (Omar et al., 2020; Ometov et al., 2021). First, blocks are provably immutable. This is possible because each block contains a hash, or numeric digest of its content, that can be used to verify the integrity of the containing transactions. Next, the hash of a block is dependent on the hash of the block before it. This effectively makes the entire blockchain history immutable, as changing the hash of any block (Ojugo, Yoro, Okonta, et al., 2013; Okuyama et al., 2014;

Omar et al., 2021).

1.2. Electronic Health Records (EHR)

Health data exchange provides ability to electronically transfer patient medical record among various healthcare (C. Panwar, 2018) as in figure 1. Even within a single institution, IT-system can be very complex with multiple feats that need access to clinical data (Ojugo, Yoro, Oyemade, et al., 2013). Today, most patient records are stored in disparate systems in healthcare community; And, many of these systems do not interoperate (A. Panwar et al., 2022; Polge et al., 2021). A practitioner in private practice may have difficulty retrieving whole record about a hospitalized patient. Also, a practitioner may repeat procedures a patient has undergone previously due to lack of access to patient prior records. Healthcare providers cannot afford to take an application-centric mode to interoperability by migrating major clinical applications to new systems or performing major upgrades because they will likely face challenges with scalability and performance, as additional application feat will require and consume, more resources (Oyemade & Ojugo, 2020, 2021).

Lack of interoperability can result in an incomplete understanding of an individual's or population's health needs, which can lead to poorer outcomes and higher costs. Thus, for proper communication within medical organizations and between them, it is critical to aid better patient care. Adopting universal data exchange standards to connect and integrate various data systems is a great way to achieve that (Girish Patil et al., 2022; Philipp et al., 2019; Pinna & Ibba, 2017).

Figure 1. Component of the EHR (Okonta et al., 2013, 2014; Wemembu et al., 2014)

Interoperability is the timely and secure access, integration and use of EHR so that it can be used to optimize health outcomes for individuals. Comprehensive data standards in healthcare bring the industry one step closer to achieving seamless interoperability (Ojugo & Otakore, 2018a, 2018b) from individual medical facilities to the national level. The goal of health information exchange is to facilitate access to (Suleiman & Reza, 2019) and retrieval of clinical data to provide safe, timely, efficient, effective and equitable patient-centred care (Braddock & Chambers, 2011). Health information exchange can also be used by public health authorities to assist in the analysis of the health of populations (Nassar & Al-Hajri, 2013).

1.3 Study Motivation

The study is motivated (Ojugo, Eboka, et al., 2015a, 2015b) as thus:

1. The unwillingness of stakeholders to disclose accurate data and processes on the rice value-chain – has led to the unavailability of data for extensive study. We wrote a non-disclosure agreement with the Lily's Hospital Warri to get the requisite data needed. To combat this – we use a hyper-ledger fabric framework.
2. Previous studies employ a centralized model, which does not provide the assured user-trust level, transparency, and transaction security that is required to ensure drug quality and safety. This study

ensures drug safety and quality via its decentralized model.

3. The Nigerian medical practitioners has no supply-chain management system. With no control of such asset, prices and quality becomes erratic with all forms of hikes and volatility birthed by monopoly. These, in turn threatens drug shortage, availability, quality, and security.

Our study seeks to avert such via the design of a decentralized mobile system – with such data, accurately and timely disseminated to users by various stakeholders. We implement an electronic health information record system for improved service delivery so that transaction authentication and validation will ensure data confidentiality, privacy, interoperability etc.

2. MATERIALS AND METHODS

2.1. Proposed Electronic Medical Records Blockchain Ensemble

We employ a 3-tier framework to model our blockchain for the medical records exchange. The blockchain creates a secure, transparent space for the medical records and serves as its hidden focal database to aid authentication of exchanged data, security and storage. The chain-codes respectively, the framework consists of a 3-tier n-client that aids effective transfer of medical records via the blockchain. The logic layer processes data by interfacing with the hash-codes in each blockchain to ensure integrity of the medical records. Each hash-code is generated via the hyper-ledger fabric which maps an input of varying length (i.e. a patient's medical data) to a hashed output of fixed length. This hashed output value of the record is then morphed when the block of data for the medical record changes. The nodes on the blockchain then inspects and validates any new medical record as either a store or retrieve transaction request. Each request is filed via a distributed consensus by a variety of validating nodes (as no single node on a chain validates or has central control of the network). Thus, making it tedious for medical records to be altered, distorted, corrupted, compromised and/or stolen (Abakarim et al., 2018; Abbasi et al., 2016; Albladi & Weir, 2018).

We created a user-interface to help effectively manage data memory access, server-side procedures, and storage; while, keeping each as an autonomous segment on isolated stages using n-fat client framework (K. W. Brown & Armstrong, 2023; W. Brown & Armstrong, 2015). Our 3-tier design allow each layer to be redesigned or supplanted freely without system downtime. Our design architecture is thus (Singh et al., 2020; Stanisławek et al., 2021): (a) the client module – which identified data with allowable services accessible on the app. This layer enables a user interact with other layers in the system by sending user query results via a P2P network, (b) the application Server yields the business logic of the blockchain (Ojugo & Eboka, 2021). It controls the application and yields smart contracts using the hyper-fabric ledger, and (c) the blockchain database houses the business logic – acting as a database server for data storage and recovery (Alakbarov & Hashimov, 2018; Datta et al., 2021; Joshi et al., 2021; Ojugo & Yoro, 2020b; Pradeepa & Parveen, 2020).

2.2. Proposed Structure and Chaincodes

The chain-code(s) as in figure 2 details transition of records between actors (i.e. patient, practitioner, database), and how medical records are distributed and changes their state from one stakeholder to another. These transactions use the smart-contracts logic to execute and regulate these transitions, and yields traceability, transparency and efficiency of these records as they move between these unique states (Ojugo & Yoro, 2021). The records and states are stored in the hyper-fabric ledger. Details of the chain-code structure is as thus (Despoudi et al., 2021; Wright & De Filippi, 2015).

1. **Stage 1: Ledger State** – The medical record represents a set of properties with assigned values that creates a unique keyset as well as the state of the patient

record. The patient_list is the complete keyset, with its state initialized as a record in the world state on the hyper-fabric ledger. This record supports several states with attributes that allows the same ledger in its world-state to hold various records of the same patient. This – ultimately makes possible the capability of the system to evolve and update its state(s) and structure.

2. **Stage 2: Proof-of-Trust** – With a variety of roles to include (and not limited to) patients, practitioners, application, users (i.e. medical personnel, nurses etc) and the varying transaction(s) – the smart contract must have enshrined therein it procedures for: (a) transition of the patient records between the actors, (b) how different business interests must approve a transaction, and (c) how each individual state keys work. It implies that the chain must set a rule in the namespace to define a business logic or transaction that processes a specific patient_record as well as set another to update all retrieved/processed record assets to portray trust relations of the transactions.
3. **Stage 3: Smart Contract** – Here, a smart-contracts code set all valid states for a patient record and the logic that transitions it from a state to another. Smart contract sets up key-business processes and information to be shared across various actors interacting on the network. It defines the various states of a business manages the various processes to move an asset/record between these states. In the BEHeDaS network, the same smart contract is shared and used by the different nodes and by the different applications connected therein. Thus, it jointly executes a shared business data and process. All members of the network must agree a specific version of smart contract to be used.

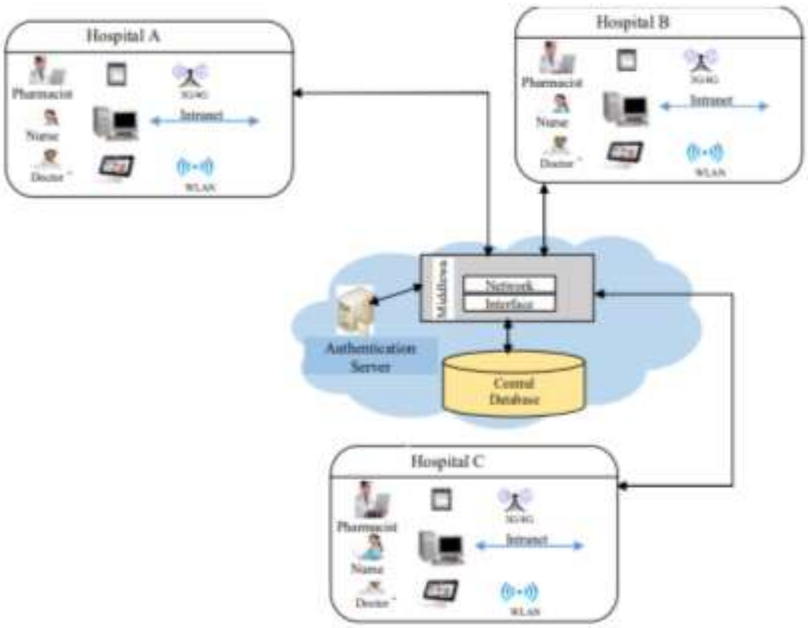

Figure 2. Block diagram of the proposed system

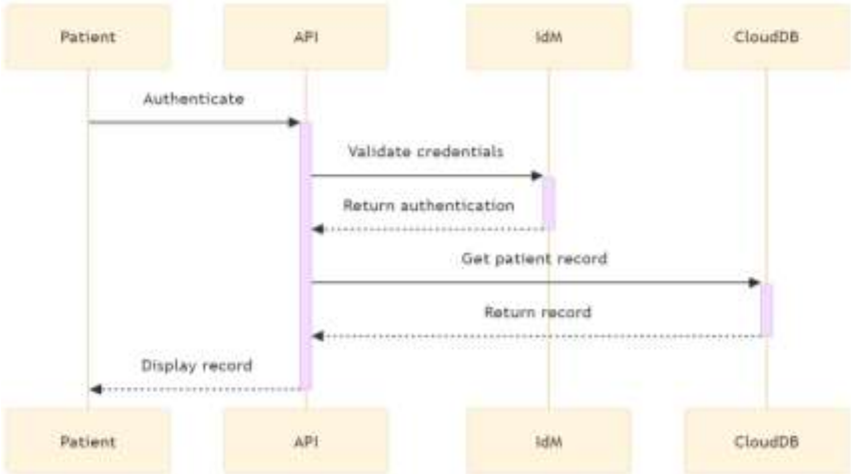

Figure 3. System flowchart of the proposed system

2.3. The Activity Diagram

An activity diagram represents a series of actions or flow of control in a system similar to flowchart or a data flow diagram. The activities modelled can be sequential and concurrent (Chevalier et al., 2003; Tarafdar & Zhang, 2005). Figure 3 shows the activities performed by each entity/class of the system and these activities are discussed thus:

1. The health personnel and patient attempt to login by entering their respective usernames and passwords, and await authorization from the blockchain database. If the username and password is invalid it aborts the operation but if valid the users (health personnel and patient) gains access into the system and are assigned individual privileges.
2. The health personnel views patients' medical history, diagnose, run tests on the patient and then upload the medical results into the system. The blockchain encrypts the medical result and shares to multiple participants in the network for consensus (Ibor et al., 2023).
3. The patient views the medical result uploaded by the heath personnel and can request for modification in biodata. The request is sent to the blockchain database and propagated across the network for subsequent approval or decline of the request. If the request is approved the changes are effected otherwise the operation is aborted. One participant cannot make changes without the consensus of other participants in the network, otherwise the data is said to be compromised. (Ojugo & Yoro, 2020a, 2020c).

3. RESULT FINDINGS & DISCUSSION

3.1. Result Findings and Discussion

3.1.1. Response Time

This performance metric seeks the time interval between a user's request and the actual time a response is fed back. To achieve response time from a Database Query, a HTTP Page, file downloads from FTP and Email Server was tracked as in figures 4 and 5 respectively using two scenarios.

Figure 4. Response time with 2500-users

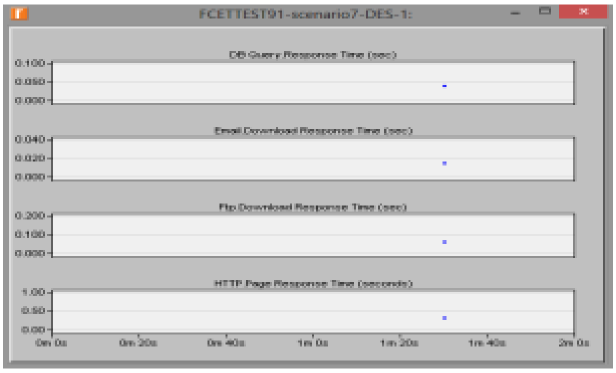

Figure 5: Response time with 7500-users

For case-1, the response time for our database queries was about 0.38secs, for email download 0.008secs, 0.052secs for file download and 0.32secs for page retrieval; conversely, for case-2, there was a longer response time as it took about 0.40secs for database queries, 0.015secs for email, 0.060secs for file download and 0.35 seconds for http retrieval. There was no significant difference in the response time for the various applications in both scenarios. With the results as above, we can conclude that the response time even with a doubled population is still very fast and the system is highly scalable. Table 1 paints a vivid picture of the simulation results.

Table 1. Scalability Result

Items	Scenario 1	Scenario 2	Scenario 1	Scenario 2
	Time Secs	Population	Time Secs	Population
DB Query	0.38	0.40	3512	7230
Email	0.008	0.015	3512	7230
FTP	0.052	0.060	3512	7230
HTTP	0.32	0.35	3512	7230

3.1.2. Application Throughput

Throughput is the actual transfer rate of data in a medium over given a period of time. Being another performance metric test, throughput test is essential because the capacity of a network can be affected by interference and errors, thus making the stated capacity quite different from the actual capacity. For throughput, the data transfer rate of the four LAN segments were analyzed as in Figure 6 and 7 respectively.

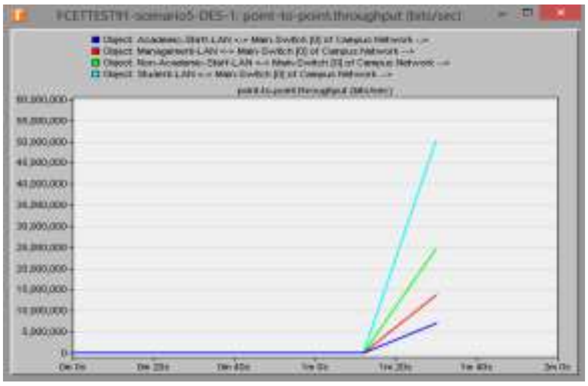

Figure 6: Throughput test for scenario 1

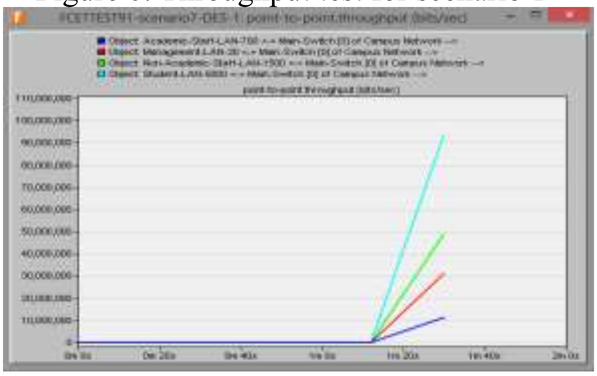

Figure 7. Throughput test for scenario 2

In scenario 1, the highest data transfer rate or throughput was about 50,000,000 bps (i.e. about 47.68mbps) – coming from the student LAN; while, lowest came from the management LAN with about 7,000,000 bps (i.e. about 6.68 mbps). For scenario 2, the highest throughput came from the student LAN with about 94,000,000 bps (i.e. 89.65 mbps), and lowest still came from the management LAN with about 12,000,000 bps (i.e. about 11.44 mbps) as shown in table 7. This is expected because the traffic was doubled in scenario seven (Cerf, 2020; Charan et al., 2020; Manickam et al., 2022).

3.1.3. Application Throughput

The ping command is used to reach the different nodes on the network. It sends Internet Control Message Protocol to different devices across the network. Figure 10 shows its execution (Ferrari et al., 2012; Hurt, 2019; Kakhi et al., 2022).

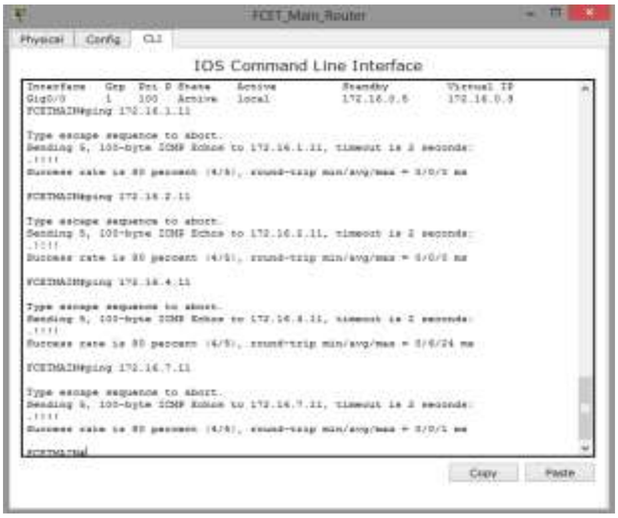

Figure 8. Reachability Test for Network

From the diagram, we can clearly see that different nodes were sent echo request, and an eighty per cent (80%) response rate was gotten. This was solely because it was the first time. Subsequent echo request had a success rate of a hundred per cent. This clearly shows that the different nodes were reachable (Ojugo et al., 2015; Ojugo & Eboka, 2019b; Yoro & Ojugo, 2019).

4. CONCLUSION

We present a palliatives support system based on a permissioned blockchain framework. Our contribution is thus: (a) we used the hyper fabric ledger for permissioned blockchain ledger to record world-state key values of generated blocks on the chain, (b) transformed each records using the key-pair value for the world states to identify patient(s) record, and (c) we used a blockchain support system for patient medical records as Health Information system to aid interoperability. The ensemble sought to tackle the challenges of interoperability, security, confidentiality and privacy of patient records among healthcare facilities in Nigeria – through a high-performance, open-sourced, and user-friendly permissioned chain support.

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