BLOCKCHAIN ENABLED DIABETIC PATIENTS' DATA SHARING AND REAL TIME MONITORING

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ABSTRACT

According to the World Health Organization worldwide diabetes report, the number of diabetic patients has surged from 108 million in the 1980s to 422 million in 2014. According to researchers, the numbers will continue to climb in the next decades. Diabetes is a sickness that requires long-term self-care and close monitoring to be appropriately put under control. As a result, continuous monitoring of blood sugar levels has the potential to save millions of lives. This paper proposes a Blockchain-based platform that connects the patients, healthcare practitioners (HP), and caregivers for a continuous monitoring and care ofdiabetic patients. It lets the patients to securely connected to HP for the purpose of remote patient monitoring (telemedicine), whilst preserving patient data privacy using the blockchain technology. IoT sensors are used to read sugar levels and store these data in a tamper-proof immutable ledger (Hyperledger). This platform provides an End-to-End movement of the patient's data. That is, from the point where it is formed (sensors) to the point it ends up in the HP side. It gives patient a control-and-track function to maintain/track data movement. It provides a unique feature in allowing the patient to keep track of the private data and to pick who they want to share the data with and for how long (and for what reason). The platform is developed in two stages. Initially, the concept is implemented using the Hyperledger Fabric. Then, a Blockchain based on a novel Proof-of-Review (PoR) consensus model is included on to provide efficient performance and scalability in the Hyperledger fabric. Essentially, this proposed platform is to alleviate the pain points in traditional healthcare systems in the scopes of information exchange, data security, and privacy maintenance for real-time diabetic patient monitoring.

KEYWORDS

Blockchain, Consensus Protocols, Secure Data Movement, Real-time Monitoring, Hyperledger.

1. INTRODUCTION

Blockchain technology is one of the most talked-about breakthroughs in decentralised network with a bright future. It draws attention since the Nakamoto Bitcoin concept in 2008 [1]. Blockchain will account for 10% of global GDP by 2027 [2], according to the World Economic Forum [3]. Blockchain [4]. introduces a revolutionary data storing, monitoring, and transaction (digital transaction) procedure between two parties that does not require the use of a third-party broker. Aside from cryptocurrencies, Blockchain has gained momentum in a variety of areas with significant advancement including insurance [5], healthcare [6-8], IoT [4, 9, 10], supply chain, transportation, and certain government agencies. Blockchain with IoT has compounded the healthcare industry with an exponential growth. Indeed, the implementation of Blockchain has

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enhanced the healthcare industry through numerous applications such as remote patient monitoring, real-time patient data aggregations or processing, medication supervision, and so on. Among others, remote patient monitoring is gaining popularity due to the COVID-19 pandemic situation that patients are not advisable or not safe to be admitted to hospitals for treatment.

It is predicted that chronic disease-related deaths would increase by 17 percent over the next ten years, affecting about 64 million individuals, and diabetes is regarded as one of the serious chronic disorders. The number of diabetic patients has increased from 108 million in the 1980s to 422 million in 2014, according to the World Health Organization's global diabetes report [11]. Researchers predict that the number will continue to rise in the coming decades. According to the International Diabetes Federation (IDF), diabetes prevalence among persons aged 20 to 79 was 9.3% in 2019, with a predicted increase to 10.9 percent, or approximately 700 million people, by 2045 [12] [13]. Diabetes is a serious public health issue in Malaysia. Diabetes is expected to affect 21.6 percent of Malaysia's adult population by 2020 [14] [15]. Diabetes, if left untreated, can lead to a number of major health consequences, including heart disease, renal failure, nerve and blood vessel damage [16]. Diabetes is a severe condition that requires long-term self-care and close monitoring for it to be properly controlled. The absence or lack of continuous monitoring, in terms of regular testing of blood glucose levels and being checked at the appropriate frequency by HP, the patient's life could be in jeopardy. Continuous monitoring of diabetes and blood sugar level has the advantage in saving lives.

It has been acknowledged that the use of ICT in healthcare data exchange increases the volume of data that floods the Internet. This is causing additional concerns in data security and data privacy. We believe that the patient should be allowed to regulate his or her health data because these data can be very sensitive and can be crucial to a patient per se. Examples existed in documents, testifying unauthorized disclosures and leakages of personal healthcare data. According to the Health Insurance Portability and Accountability Act (HIPAA), 13,236,569 medical records were compromised in 2018, more than double the 5,138,179 records exposed in 2017 [17]. In the Proetus Breach Barometer study [18], 140 million medical data were compromised in 2015.

Decentralization, anonymity, tamper resistance, auditability, transparency security, immutability, and trust less infrastructure are all properties of blockchain. These features may be used on the Internet of Things (IoT) as a critical technology [19] to overcome healthcare data exchange with tempered-proof interoperability for the benefit of the healthcare business operations.

For permissioned/private settings, blockchain technologies such as Ethereum [20, 21],, Hyperledger Fabric [22], and Corda are available. The Hyperledger Fabric [23] [24] is the most well-known and commonly utilised platform for commercial applications. It has been thoroughly evaluated in a variety of business settings, including supply chain management, healthcare [25],, and so on. Over 400 proof-of-concept and commercial distributed ledger applications in a variety of sectors and use cases have been implemented [24, 26]. HLF (Hyperledger Fabric) is a private (permissioned) blockchain system with an architecture that may be used to build industry-based blockchain applications [24] [27]. The HLF is adaptable, allowing for the addition or removal of components as needed, such as consensus and membership services. It uses the Docker container approach to allow smart contracts (chaincode) to create the application logic for the system [28].. The network's transactions are kept secret by using a channel isolation approach, which ensures that only authorised nodes of a certain channel may see the transaction.

This paper proposes a Blockchain-based platform that brings together stakeholders such as patients, HP, and caregivers for the continuous monitoring of diabetic patients. It lets patients to securely connect to HP for remote patient monitoring (telemedicine) and preserving patient data privacy with blockchain technology. Essentially, the purpose of the proposed platform is to alleviate the pain points in traditional healthcare systems in the scopes of information exchange, data security, and privacy maintenance leveraging on real-time diabetic patient monitoring. The platform allows IoT sensors to sense sugar levels and store the sensed data in a tamper-proof immutable ledger (Hyperledger). This paper focuses on the End-to-End movement of the patient's data from the point where it is formed (sensors) to the point that ends up in the healthcare provider's side. The patient is granted a control-and-track feature to maintain and track his/her data movement. This feature is a unique approach that allows the patients to keep track of their private data and to decide who they want to share the data and for how long (and for what reason). This concept will be implemented using Hyperledger Fabric, and then, a novel Proof of Review (PoR) consensus model [29] Blockchain will be built to improve the efficiency, performance, and scalability of the Hyperledger fabric.

The rest of the paper is organised as follows. Sections 2 discuss the related work, section 3 and 4 discuss the proposed model and implementation of proposed model, and section 5 conclude the paper.

2. RELATED WORK

Some of the research works related to the proposed approach are briefly described in this section. The study in [30] proposed a 3-phase Blockchain enabled diabetes detection system that includes: registration, user identification using HER, and IoT data upload with Blockchain. After completing all three phases, machine learning algorithms were introduced to identify diabetes in patients and securely exchange the data within healthcare practitioners.

In [31], IoT, Blockchain, and cloud technologies were used to provide healthcare and tele-medical laboratory services in a hospital setting. IoT sensors collect and communicate vital signs and physiological information, allowing clinicians to give relevant, transparent, and safe medical treatment to their patients. This decentralised platform employs the Ethereum hybrid network certification approach, which provides a faster response time and lower cost than alternative methods. In a secure healthcare environment, communication is created between IoT nodes, servers, and the blockchain network. A front-end web application allows users to connect to the blockchain network.

According to the researchers in [32], BlockIoT is a solution that employs blockchain technology to communicate previously unavailable and centralised data from medical equipment to EHR systems, providing clinicians with better insight and improving patient outcomes. The Application Programming Interface (API) includes a customisable endpoint for all incoming medical device data, a distributed file system for data resilience, and knowledge templates for analysing, identifying, and displaying medical device data to providers.

The research in [12] looked examined diabetes patients' use of smartphones, as well as their plans to use them for self-care, monitoring, and management. The majority of participants in the study have a mobile phone (97.5%) and a smartphone (87%) and use the Internet on a daily basis (83.5 percent). The majority of participants utilised apps for meal planning (85.5%), glucose monitoring (76.5%), and scheduling diabetes appointments (76.5%). (76.5 percent).

A blockchain-based infrastructure proposed in [33] used an off-chain storage option to facilitate medical data exchange. Only critical information will be stored on the blockchain network, whilst all medical are stored on the cloud. The cloud operation module oversees all activities involving with the cloud storage. The recording module has six indications, including blood sugar, medication, nutrition, weight, exercise, and sleep, as well as indicator recording capabilities.

According to the experts in [34], there are a variety of ways that IoT and Blockchain technologies may be employed in the healthcare industry to improve overall performance and improve the present sector. Three major areas (healthcare) where their IoT and Blockchain technology might be used are (a) remote patient monitoring, (b) drug traceability, and (c) medical records management. The revolutionary usage of IoT and blockchain technologies in the healthcare business was also looked into.

HealthMudra [35] is an algorithm for developing the diabetes prevention guidelines. Health Mudra comprises a blockchain-based platform with optimization and machine learning algorithms. Diabetes can be avoided by following physicians' advice and reducing the symptoms. A decentralised Blockchain database was used to store information obtained from a large number of doctors to ease diabetes symptoms. Patients who use blockchain take ownership of their medical records.

The work in [36] presented a solution for addressing inefficiencies in existing techniques for exchanging healthcare data by employing a data-sharing system called MedChain, which mixes blockchain, digest chains, and a structured P2P network. MedChain was utilised to create a session-based healthcare data-sharing strategy that allows for data sharing flexibility. The results of the evaluation suggested that MedChain can improve productivity while also meeting data security needs.

A framework presented in [16] showed the integration of IoT and Blockchain to collect health data and share the data with healthcare organisations for daily smart therapy. To guard against hostile devices, the entire team concentrated on patient privacy and device security. Consequently, the patient may be guaranteed that his health data is collected on a regular basis, and in certain cases, automatically.

The Internet of Things (IoT) is being hailed as a game-changer in the healthcare industry, and the project in article [11] was to assess and analyse how IoT technology and its solutions might help patients with chronic conditions live better lives. The findings suggested that IoT can help in continuous glucose monitoring, as well as tracking patients' activities and diet to improve their lifestyle.

Blood sugar measurements may be gathered from distant CGMs and retrieved remotely utilising an IoT CGM-based system for mHealth as reported in the works of [37]. As a result, this technology allows patient monitoring and warning in the event of a potentially dangerous situation. Thanks to the blockchain and the recommended CGM-based system, it is feasible to supply a transparent and trustworthy blood sugar data source from a population in a quick, flexible, scalable, and low-cost manner. New mHealth apps for diagnosis, patient monitoring, and even public health activities might be enabled by crowdsourced data, all of which could help advance diabetes control and raise worldwide awareness of the disease's expanding prevalence.

A considerable majority of noncommunicable disease (NCD) diagnoses are erroneous, undesirable, or unnecessary, according to a study by researchers in [38],. As a result, they suggested a Proof of Disease (PoD) consensus technique based on Ethereum that includes a single instance of truth that computers can comprehend. It addresses a number of issues that have yet to be addressed by electronic health records (EHR) and health information exchange (HIE). This medical system will assist in meeting all of P6 medicine's complicated requirements (participatory, personalised, proactive, preventative, predictive, and precision medicine) and there by lessen sickness load.

Utilising the blockchain-based smart contracts, the works in [39] suggested a unique platform for patients' vital signs monitoring. The system was designed and built using Hyperledger fabric for enterprise-distributed ledger platform applications. This technique provides patients with a comprehensive, immutable medical history record, as well as a global access to medical information at any time and from any locations. The Libelium e-Health toolset was used to collect physiological data. A common benchmark tool called Hyperledger Calliper was utilised to assess the performance of the intended (and developed) system.

SMEAD system [40], an end-to-end safe solution for aiding diabetes patients. It contains devices that measure a number of markers, enabling for the tracking and forecasting of a patient's diabetes status. In the recommended approach, a MEDIBOX was used to configure the correct dosage and send an alert to consumers reminding them to take their prescription on time. The insulin dosage is stored at a safe temperature and is tested on a regular basis using the process described above.A Blockchain-based disruptive technology that offers cryptographic security and formalised data access through smart contracts for medical communities was carefully built to keep all data secret and to allow access to this data by physicians and other trustworthy parties. An alert is sent to caregivers via social media in the event of an emergency, such as skipping a medication, having abnormal blood sugar levels, or any security breach.

Table 1: Illustrates the critical comments on similar platforms and comparison with the proposed system.

Ref	**Year**	**Critical Comment**
[30]	2021	Blockchain enabled diabetes detection system to consist of 3-Steps. After completing all steps, machine learning algorithms were used to identify diabetes in patients.
[31]	2020	IoT sensors collect and communicate vital signs and physiological information, allowing clinicians to give relevant, transparent, and safe medical treatment to their patients. This decentralised platform employs the Ethereum hybrid network certification approach and A front-end web application allows users to connect to the blockchain network.
[32]	2021	BlockIoT is a solution that employs blockchain technology to communicate previously unavailable and centralised data from medical equipment to EHR systems, providing clinicians with better insight and improving patient outcomes.
[12]	2021	Here examined use of smartphones by diabetic patient. The findings are majority of participants utilised apps for meal planning (85.5%), glucose monitoring (76.5%), and scheduling diabetes appointments (76.5%).
[33]	2021	There are 6 six indications, including blood sugar, medication, nutrition, weight, exercise, and sleep stored on off0chain storage option to facilitate medical data exchange. Only critical information will be stored on the blockchain network, whilst all medical are stored on the cloud.
[35]	2020	HealthMudra is an algorithm for developing the diabetes prevention guidelines. A decentralised Blockchain database was used to store information obtained from a large number of doctors to ease diabetes symptoms. Patients who use blockchain take ownership of their medical records. It also utilises ML algorithm,
[36]	2019	MedChain was utilised to create a session-based healthcare data-sharing strategy that allows for data sharing flexibility. The results of the evaluation suggested that MedChain can improve productivity while also meeting data security needs.
[16]	2018	A framework in this showed the integration of IoT and Blockchain to

		collect health data and share the data with healthcare organisations for daily smart therapy including Blood sugar levels.
[11]	2019	The project was to analyse IoT technology, and its solutions might help patients with chronic conditions live better lives. The findings suggested that IoT can help in continuous glucose monitoring, as well as tracking patients' activities and diet to improve their lifestyle.
[37]	2018	New mHealth apps for diagnosis, patient monitoring, and even public health activities might be enabled by crowdsourced data, all of which could help advance diabetes control and raise worldwide awareness of the disease's expanding prevalence. The blockchain and the recommended CGM-based system is feasible to supply a transparent and trustworthy blood sugar.

3. PROPOSED MODEL ARCHITECTURE

This paper proposes a healthcare platform by utilizing the IoT devices (sensors) and the Blockchain technology. The platform compromises of 4 different layers. IoT (Sensor) devices layer, Gateway layer, Blockchain, and the Application layer. IoT devices layer comprises of sensors to measure blood sugar and other necessary vitals sign for diabetic patient, and it enables users (patients) to communicate the data to next layer. Gateway layer configures IoT devices (sensors) and connects them to the next layer. Basically, it allows IoT devices to pass data to the Blockchain layer. Moreover, Blockchain layer comprises of Blockchain related services which include, consensus mechanism [41], user identity management, IoT sensors information, distributed ledger storage, and smart contracts. The distributed ledger is a shared and replicated ledger, that is distributed across the entire Blockchain network. Every participant stores a copy of the ledger. Any changes in the distributed ledger should be updated in entire Blockchain after achieving consensus on the state of the ledger in within the ledger. This distributed ledger stores the patients’ vital sign data collected by the IoT sensors. The smart contract is a program/code triggered by itself or external input to manage, store, access and modify the data on the distributed ledger. There may be many smart contracts, depending on the requirements of the diabetic patients i.e., event or notification, it will be triggered on certain time to notify patients to measure data or sending notification to HP every time a new Block is added to the ledger. API provides the designing services in the healthcare blockchain platform, allowing clients to interact with the app and control the blockchain network. The application layer is a user interface for visualizing vitalsign data for managing and controlling of healthcare devices. Basically, the Blockchain technology enables all the stakeholders to communicate, and share required data in a secure way. A P2P network, consensus methods, and asymmetric cyphers are used to communicate in the blockchain. The last part of Blockchain layer is Remote patient monitoring (RPM). It allows patients and HPs to connect with each other in the event of any emergency or unbalance data.

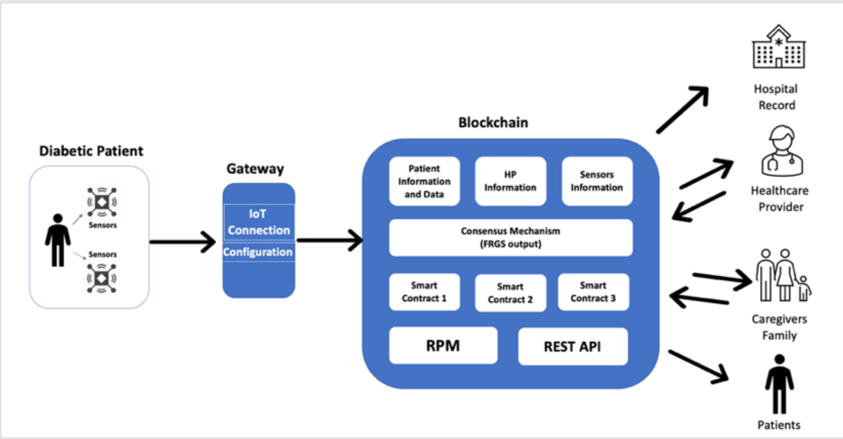

Figure 1: The proposed conceptual architecture

4. IMPLEMENTATION OF PROPOSED MODEL

The implementation of the proposed model is divided into two different phases. In the 1st phase, implementation will be done using the infamous private blockchain tool – Hyperledger fabric, and in 2nd phase, a custom Blockchain will be developed and designed using our novel Proof of Review consensus model. The performance, efficiency and scalability will be compared in both phases. Figure 2 illustrates the implementation of proposed Blockchain enabled diabetic patient monitoring platform in the Hyperledger Fabric. In this scenario, the Hyperledger Fabric is used as Blockchain platform along with healthcare sensors to measure vital signs. The essential components in Figure 2 are described below.

IoT Devices: IoT devices are different healthcare sensors, which may include blood pressure sensor, SPO2 sensors, glucometer sensor, body temperature sensor etc. As per the literature, all diabetes vital signs are effects or may get effected by blood glucose. Therefore, it is essential to monitor all these important vital signs. Here, individual (patient) will use IoT devices to measure all the vital data and forward them to Hyperledger (Blockchain).

Gateway: Raspberry Pi (RPi) defines as a series of single-board computers that are to connect the IoT devices. In this project Raspberry Pi will be used at the Gateway working as a bridge between Hyperledger and the IoT devices. Basically, it creates connection and configuration with sensors and Blockchain network.

Hyperledger Fabric: All required tools and components are deployed using the HLF LTS version. This comprises organisations with six peers: two committing peers (4 committing peer) and two endorsing peers (2 endorsing peer), as well as four CouchDB instances. With the ordering service, the RAFT consensus process would be used. Hyperledger provides the Representational State Transfer (REST) Application Programming Interface (API) capabilities to expose services to client applications for additional analysis. The client application, notification, may access all of the services written in the smart contract using REST API. In addition, the fabric client communicates with the fabric network via Google Remote Procedure Calls (gRPC). For various functions, several smart contracts will be established.

Smart Contracts: The business logic for smart contracts in transactions is defined by the Hyperledger Fabric. The Hyperledger Fabric Client SDK Node.js was used to connect with Hyperledger Fabric, and the smart contracts in this study were written in GO.

- SC1: It will create different notifications i.e., reminder, notifying HP to view data, notification on any unbalance data.
- SC2: It will allow patient to track their data and give permission/access to HP for certain predefined time.
- SC3: It will allow HP to write feedback and input on any data.

Application: All stakeholders, including patients and healthcare providers, will have access to data from the application side. This layer will either be a web application or a mobile application. This will provide aggregated data from the patients' vital signs. This layer also allows users to connect to healthcare services via the telemedicine component.

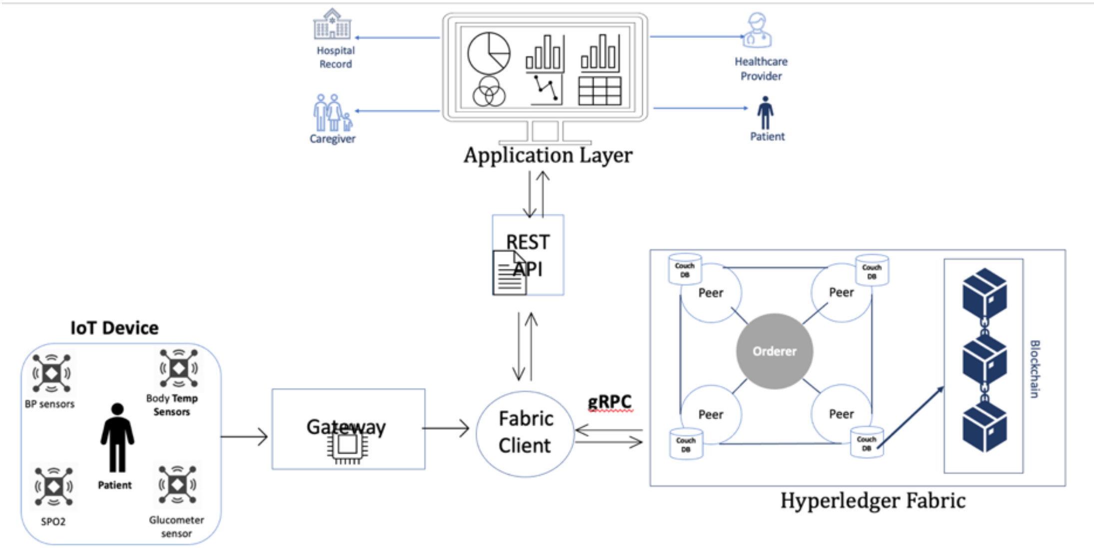

Figure 2: Implementation model of Blockchain enabled diabetic patients monitoring.

5. CONCLUSIONS

To conclude, this paper proposes a conceptual Blockchain-based framework that brings together stakeholders such as patients, HP, and caregivers for the continuous monitoring and care of diabetic patients. It comprises remote (diabetic) patient monitoring (telemedicine) features by utilizing blockchain technology. The IoT sensors will extract sugar levels, and possible other vital data, and store them in a tamper-proof immutable ledger (Hyperledger) focusing on the End-to-End movement of the patient's data from the point where it is formed (sensors) to the point where it ends up in the healthcare provider's side. The system gives the patient a control-and-track feature to maintain track of his/her data travel. It provides a unique feature that allows the patient to keep track of their private data and pick who they want to share it with and for how long (and for what reason). The implementation will take place in two phases. The initial concept will be implemented using Hyperledger Fabric, and then, a n novel PoR Blockchain consensus model will be built to compare the efficiency, performance, and scalability with Hyperledger fabric. It should be mentioned here that in this paper only the first phase of implementation has been presented. Rest of the implementation will be presented in future works.

6. FUTURE WORK

The proposed approach is now undergoing implementation and in-depth/detailed studies. To evaluate and verify the suggested approach, experiments and simulations will be employed. The suggested approaches, the implementation, and experimental results are to be published in future articles.

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