IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 13 April 2023, accepted 15 May 2023, date of publication 7 June 2023, date of current version 16 June 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3283776

RESEARCH ARTICLE

BCGeo: Blockchain-Assisted Geospatial Web Service for Smart Healthcare System

SOUBHAGYA RANJAN MALLICK[1], RAKESH K. LENKA[1], VEENA GOSWAMI[2], SURAJ SHARMA[3], (Member, IEEE), ASISH KUMAR DALAI[4], HIMANSU DAS[5], AND RABINDRA K. BARIK[2], (Member, IEEE)

[1]Department of Computer Science and Engineering, International Institute of Information Technology, Bhubaneswar 751003, India
[2]School of Computer Applications, KIIT Deemed to be University, Bhubaneswar 751024, India
[3]Department of Computer Science and Engineering, Guru Ghasidas Vishwavidhalaya, Bilaspur, Chhattisgarh 495009, India
[4]School of Computer Science and Engineering, Vellore Institute of Technology–AP University, Amaravati 522237, India
[5]School of Computer Engineering, KIIT Deemed to be University, Bhubaneswar 751024, India

Corresponding authors: Rakesh K. Lenka (rakeshkumar@iiit-bh.ac.in) and Asish Kumar Dalai (asish.d@vitap.ac.in)

ABSTRACT Most recent research on healthcare systems has focused on integrating the Internet of Things (IoT), Blockchain technology, and cloud computing to enhance the performance of IoT devices with limited resource availability, create smart healthcare platforms, and offer patients the best possible healthcare service. Modern healthcare systems use large-scale sensor devices to address many challenges brought on by the conventional delivery of healthcare services. Most studies have lately identified data collection, massive data processing, geolocating, access management, device prioritization, and storing as primary issues in most IoT healthcare systems. Decentralization, privacy, security, scalability, trust, anonymity, and building geospatial-based intelligent healthcare systems for patient care are significant difficulties that most healthcare systems today must overcome. Blockchain technology in healthcare platforms is noteworthy and innovative since it opens platforms for data privacy, anonymity, and validity through the consensus process. In this work, we proposed a novel decentralized Blockchain-enabled geospatial service architecture for smart healthcare systems called ***BCGeo***. The proposed framework offers an online geospatial healthcare service for residents of Bhubaneswar, a city in India, who are newcomers to the city and are less familiar with its local healthcare organizations. An analytical queueing method prioritizes serving Critical patients more than other patients. In contrast to previously proposed frameworks, the proposed framework includes immutability, scalability, geospatial mapping, patient prioritizing, and decentralized privacy protection policies for addressing the technical challenges in most of the current healthcare systems. Additionally, it explains the performance analysis of ***BCGeo***. It includes graphs showing the various possible outcomes of arithmetic operations, performance measurement, and experimental results on the proposed architecture.

INDEX TERMS Blockchain, geospatial web services, medical data, healthcare, queueing model, IoT.

I. INTRODUCTION

The widespread adoption of Internet of Things (IoT) technology in various applications has profoundly impacted the current generations. IoT applications use sensor devices that are low-power, low-cost, more efficient, don't require human involvement, and are interconnected over a large geographic region. The IoT makes machine-to-machine and machine-to-human communication possible, where sensor devices or actuators facilitate human interaction. Emerging technologies are essential in the demanding field of healthcare. Many technologies, including edge computing, cloud computing, fog computing, machine learning, and Blockchain technology, are integrated with the IoT to create intelligent healthcare systems [1], [2]. Healthcare organizations are using more and more sensor-based medical equipment as they adopt cutting-edge technologies and strive to give patients the best care possible [3], [4]. IoT-enabled

The associate editor coordinating the review of this manuscript and approving it for publication was Mueen Uddin.

healthcare solutions can provide remote patient tracking, monitoring, alerting, assistance, and 24/7 healthcare service. To integrate sensor-based medical equipment with IoT healthcare systems, several wireless protocols, including CoAP, MQTT, AMQP, XMPP, HTTP, Zigbee, Zwave, WiFi, LoRaWAN, SigFox, and Bluetooth, are available [5], [6]. Data collection and processing are challenging or occasionally fail for a large volume of data with the conventional data management method since the number of patients worldwide is steadily rising daily. Most IoT systems use centralized frameworks. If the central server goes down or malfunctions at any point, the entire system's processing will slow down or occasionally stop working altogether. In the IoT based healthcare systems, it is considered a significant challenge. IoT systems face scalability, trust, interoperability, stability, and immutability issues when large-scale devices are connected to the system [7]. To address the technical issues with IoT devices, a new emerging technology called Blockchain was introduced [8].

Healthcare costs, remote patient monitoring, tracking, treatment quality, and disease surveillance are all significantly impacted by a timely Health Information Exchange (HIE) between doctors, pharmacists, patients, nurses, lab technicians, and insurance providers of healthcare systems. Blockchain is digital ledger technology (DLT) introduced in healthcare sectors to address the technical challenges of IoT systems. Decentralized, distributed, and immutable properties of Blockchain technology overcome the security, privacy, trust, availability, reliability, and privacy issues of IoT systems [3], [9]. Healthcare industries have adopted Blockchain technology, a distributed, decentralized, and irreversible digital ledger with no single central authority in charge of managing the healthcare system. Since Electronic Medical Records (EMR) are essential and extremely sensitive, Blockchain technology allows security, privacy, trust, availability, dependability, scalability, interoperability, and stability in healthcare systems to overcome the technological limitations of IoT healthcare systems. Since Blockchain is built on cryptographic hashing techniques, each node in the network can take part in transmitting, sharing, accessing, storing, and viewing healthcare data without the need for prior verification between network members. For most Blockchain-integrated IoT healthcare applications, a smart contract is a self-executing, small piece of code written in the solidity programming language and added to Ethereum Blockchain healthcare systems. When a user connects to, transacts with, requests access to, views, stores, grants access to, or transfers any information through a healthcare platform, the predefined set of rules in a smart contract is automatically carried out with the users' consent to verify the device identity and access controls [3]. The transaction will be broadcast to all users since Blockchain is a fully distributed peer-to-peer network that performs transactions without the involvement of a third party. Once the transaction is completed correctly, it cannot be changed because of Blockchain's immutable characteristics. The consensus method employed for block formation, block validation, and transaction validation is another noteworthy feature of Blockchain technology. IoT infrastructure with Blockchain integration enables large-scale data processing, decentralized IoT systems, billions of IoT device connectivity, public device identity verification, and the removal of third-party verification [10]. Due to these technical advantages, Blockchain technology is being integrated and implemented by several IoT healthcare organizations [5]. Additionally, hospitals may open or close, merge with other healthcare facilities, or change their services or specialties, making it challenging to maintain an accurate and up-to-date list of all hospitals in a given location.

Knowing every hospital in a city or country is difficult due to the large number of healthcare facilities and hospitals in any given area. Furthermore, hospitals may close, combine with other hospitals, or change specialties, making it difficult to maintain an accurate and up-to-date list of all hospitals in a given location. Detail information about the hospitals and their specifics must be provided when providing information about hospitals in large areas, such as a city or district. Geographical Information Systems (GIS) can facilitate storing, viewing, analyzing, and disseminating hospital data and maps, which are necessary to carry out this activity using scientific approaches in a more straightforward manner [11].

To provide healthcare services for the people of Bhubaneswar city of India, or for people who are new to the city and are less familiar with its local healthcare organizations, the researchers have developed an online geospatial service with Blockchain integration for healthcare systems. An analytical queuing strategy is implemented to give Critical patients more priority than normal patients to serve them in a priority manner. For overcoming the technical issues present in most of the existing healthcare systems, this proposed framework offers security, immutability, scalability, geospatial mapping, patient prioritization, and decentralization of privacy protection policies compared to previously proposed frameworks. Along with explaining the performance analysis of ***BCGeo***, it also includes graphs illustrating the various outcomes of arithmetic operations, performance assessment, and experimental findings about the proposed architecture.

A. MOTIVATION

Traditional centralized cloud-based architecture is now being used to store data from traditional healthcare systems, which increases security threats and necessitates trusting a single authority as medical records are still primarily immobile in these systems. Most researchers have suggested that Blockchain and the IoT are the key technologies for constructing an intelligent healthcare infrastructure. Data sharing, storage, access, collection, viewing, privacy, security, dependability, device management, processing, and interchange of healthcare data are the primary research areas that most researchers in the past have studied and proposed. To our knowledge, past research initiatives did not combine a geospatial-assisted analytical queueing strategy with Blockchain integration for access mechanisms based on the criticality of the patient. In this work, the researchers used a decentralized Blockchain network with an analytical queueing model approach to deliver healthcare services based on the patient's criticality. This framework's suggested inclusion of geospatial web service capabilities enables patients to monitor and find information about hospitals in Bhubaneswar city in India, where most areas are unfamiliar to the person new to this city.

B. CONTRIBUTIONS

The researchers in this work have proposed ***BCGeo***, an IoT healthcare platform with Blockchain integration and a geographic web feature service. The following contributions are made to the structure of the current research work:

1) It proposes a novel framework for smart healthcare systems called ***BCGeo***, which uses Blockchain-assisted decentralized geospatial web service applications.
2) Additionally, it creates a model for integrated geospatial web services so that Bhubaneswar city of India's hospitals can be visualized on a map.
3) It uses an analytical queueing method for prioritizing critical patient care to ensure the greatest degree of on-demand patient care as well as a resolution for device management and scalability challenges in smart healthcare systems.
4) Moreover, it provides the performance analysis of the ***BCGeo*** and includes graphs showing the various possible outcomes of arithmetic simulations, along with performance measurement and experimental results on the proposed framework.

C. ORGANISATIONS

The rest of the paper is organized as follows. Section II explains the related work and background studies of the present research works. Section III presents the attributes and a detailed description of the Blockchain-assisted decentralized geospatial web services framework for smart healthcare systems. Section IV discusses the system model of the proposed system. Section V explains the performance analysis of the proposed framework. Section VI presents the experimental findings and performance assessment of the suggested architecture, which are based on the variability of arithmetic results in graphs. Section VII lists the findings and discussion of the proposed framework in healthcare platforms. Section VIII draws the concluding remarks of the present research paper.

II. RELATED WORK

This section briefly discusses the literature about technological challenges and advancements with smart healthcare systems. Most relevant research works have been chosen and presented in the healthcare domains. Table 1 summarizes, the objective of the research, the technological features addressed, and the availability of geospatial web service capabilities for previously done research studies in healthcare applications.

Blockchain-based COVID-19 medical record traceable and direct revocation with security and privacy mechanism was proposed by Tan et al. [12]. Authentication and access management mechanisms are implemented using encryption and decryption processes. Moreover, tracking and revoking malicious nodes have also been done here. Zhang et al. [13] have proposed a Blockchain architecture to address the security and trust challenges in networks, smart contracts, and data. A private Blockchain-based decentralized scheme was proposed by Liu et al. [14] to maintain security and privacy while sharing healthcare data. They have used OpenSSL libraries, and PBC to implement their proposed model. Biswas et al. [15] proposed a Blockchain-integrated IoT framework that restricts the transactions to directly entering into the global Blockchain by implementing local peer-to-peer networks. A secure and traceable Blockchain Interplanetary file system (IPFS) based healthcare framework was proposed by Sun et al. [16]. Attribute encryption and access control have also been implemented in this framework to retrieve healthcare data efficiently. An electronic health record (EHR) management framework with the integration of Blockchain and IPFS was proposed by Jayabalan et al. [17]. This decentralized framework is tamper-proof and secure. Access management is implemented to facilitate in-time data access by healthcare personnel and patients. Farnaghi et al. [7] have proposed a Blockchain-based public participatory GIS (PPGIS) application for the decision-making of government organizations in urban planning. Researchers have developed a decentralized application using Ethereum Blockchain. For tracing the mapped pollution and spatially identifying the intake source of real-time water pollution, Lin et al. [18] proposed an IoT and blockchain-based wireless sensor network and Geographic Information System tools. Alrebdi et al. [19] proposed a decentralized, secure, and efficient Blockchain-smart contract and interplanetary file system-based electronic medical record system for user verification, data storage, and search for a particular healthcare record. Azbeg et al. [20] proposed a secure, scalable, and efficient healthcare system BlockMedCare for remote monitoring of chronic disease patients. Ethereum Blockchain and smart contracts are used in this system to speed up the processing and storage. Blockchain hyperledger fabric-based framework was introduced by Sun et al. [21] for medical data storage and access control implementation. To reduce the overload in the Blockchain network, the IPFS is used for decentralized medical data storage. Mani et al. [22] proposed a decentralized Hyperledger fabric-based framework, namely PCHDM (patient-centric healthcare data management) for on-chain and off-chain storage of healthcare data which ensures data privacy, and scalability, and resolves the storage issues. A Blockchain-integrated three-tier network and IPFS-based framework have been proposed by Mehbodniya et al. [23] to ensure the security and privacy of the Internet of

Medical Things (IoMT) devices connected to the framework. A decentralized peer-to-peer Blockchain and IPFS-based platform has been proposed by Kumar et al. [24] for image and video sharing. Blockchain and IPFS-based agricultural product traceability have been proposed by Zhang et al. [25] implemented an evaluation function for traceability of the quality of the product and addressed the massive data storage issues with IPFS storage. Kafhali et al. [26] proposed a mathematical and analytical model of queuing to analyze the effectiveness of a fog computing system to satisfy the quality of service (QoS) requirements for every offered IoT workload.

Numerous research papers have been written on geospatial web services combined with Geographic Information Systems and web technology [27]. Users can take advantage of the geographical data, and computational resources available online through the utilization of geospatil Web services, which also enable users to automate the integration, processing, and analysis of geospatial data [28]. Additionally, it has suggested a serverless Cloud Geographic Information System technology, which has been subsequently used for the land valuation platform. On Amazon Web Services, a database known as Aurora Serverless PostgreSQL is developed to facilitate the storing, analyzing, and sharing of geospatial data [29]. Additionally, it built a web-based open-source geoinformation tool for estimating Flow Duration Curves (FDCs) in basins that have not been gauged. The FDC estimation was achieved using a regional statistical model employing multivariate regression to link basin topographic parameters, climatic characteristics, other environmental factors, and FDC features. [30]. New possibilities arise with the advent of geospatial web service technologies, which enable users to access massive amounts of Big Earth Data via the Internet and to manipulate these datasets on the server side [31].

III. PROPOSED FRAMEWORK

A. ATTRIBUTES USED IN PROPOSED FRAMEWORK

Researchers have proposed distributed, decentralized, and geospatial web feature services for Blockchain-integrated IoT-enabled smart healthcare systems depicted in Fig. 1. The attributes used in this framework are as follows:

1) *Healthcare users:* The user groups identified to link to this framework include doctors, insurance companies, pathologists, lab technicians, patients, nurses, and other healthcare users.
2) *Decentralized applications (Dapps):* In this proposed framework, a fully decentralized, peer-to-peer network-operated decentralized application (Dapp) is created using Blockchain technology. Deploying the smart contract in this decentralized environment eliminates the need for third-party verification. All the users of this framework are connected via Dapps.
3) *Priority Queue:* Based on the patient type and the level of healthcare service required, a priority queueing approach is employed in this framework to deliver healthcare service to the patients. The proposed system divides the priority into low for normal patients and high for critically ill patients.
4) *Smart contract:* To automate the framework based on the preloaded rules and do away with the necessity for third-party verifications, a small piece of self-executable code written in the Solidity programming language is being deployed in the proposed Ethereum framework. Additionally, it demands the user's device to run the terms and conditions outlined in advance.
5) *Gateways:* Gateway enables the routing of healthcare data in the proposed Blockchain network and allows various user devices to interact with the framework.
6) *Access control:* The scalability problems brought up when several devices are connected to the framework are dealt with here via access control. Additionally, critical patients receive higher priority than normal ones through the queueing approach.
7) *Healthcare Departments:* The healthcare services offered to patients vary depending on the healthcare departments. Depending on the disease he or she may suffer, a patient might connect to a specific department.
8) *Block:* All transactions carried out by healthcare users are added to an immutable, decentralized, distributed, and hash-linked ledger that is constantly growing.
9) *Proof of work (POW):* This is a consensus mechanism used in this framework for block mining. In this healthcare system, miner nodes verify and validate transactions performed by healthcare users.
10) *Blockchain:* The validated blocks are linked to each other through a hash value. As a result, a decentralized chain of blocks is produced. Every node on the Blockchain network has access to a transaction after it has been made, subject to user consent.
11) *Cloud storage:* Large numbers of devices are connected to the healthcare framework as a result of the constant growth in healthcare users. Substantial volumes of data transfers and storage are needed to support large-scale devices. Cloud storage is used for big data storage for this framework.
12) *Geospatial web feature service:* Through this service, patients who are new to Bhubaneswar or who are less familiar with the hospitals that are offering services for their sickness can locate them and receive immediate patient care, which could potentially save their lives in critical conditions.

B. FRAMEWORK DESCRIPTION

The researchers have proposed a geospatial web service framework with Blockchain support to implement distributed and decentralized processing and storage of healthcare data in modern IoT healthcare systems. This architecture connects all its healthcare users via a public Blockchain network built on the Ethereum Blockchain platform. In this framework, minor nodes compete with one another to solve the mathematical puzzles for block formation, block validation,

TABLE 1. Applications and advancements of different Blockchain healthcare models.

Author and Reference	*Year*	*Addressed Features*	*Access Management*	*Geospatial Web Feature Service*	*Purpose*
Roehrs et al. [32]	2019	Response time, Availability, Interoperability	No	No	Blockchain-based distributed PHR
Zhang et al. [33]	2020	Access control, Reliability, Authorization, Scalability	Yes	No	Attribute-based access control in Blockchain-IoT system.
Azbeg et al. [34]	2022	Security, Scalability, Encryption, Processing time, IPFS	Yes	No	Securing IoT healthcare devices using Blockchain
Egala et al. [35]	2021	Latency, Anonymity, Security, Response time	Yes	No	Secure and automated Blockchain and smart contract-based decentralized electronic health record (EHR)
Xiang et al. [36]	2022	Security, Privacy, Authentication, Access control	Yes	No	Medical data privacy using Blockchain-based authentication and access control
Rana et al. [37]	2022	Interoperability, Security, Access control, Consistency	Yes	No	Blockchain-based secure and interoperable healthcare organization using decentralized access control mechanism
Frikha et al. [38]	2021	Security, Authorization, Resource, and power consumption	Yes	No	Smart fitness and health device data collection using Blockchain integrated IoT platform
Shi et al. [39]	2021	Scalability, Trust, Identity management, Storage, Privacy, Security	No	No	Triple-trusting Blockchain-based architecture for data sharing and identity management
Wan et al. [40]	2022	Scalability, Security, Performance	Yes	No	Scalable and accountable data management of IoT devices using hierarchical Blockchain architecture
Yan et al. [41]	2020	Security, Resource consumption, Power Consumption, Mining	No	Yes	Improvement of transaction speed of IoT devices
Farnaghi et al. [7]	2020	Immutability, Tamper-free, Transparency	No	Yes	Decentralized applications (Dapps) built on blockchain for transparency, accountability, and open access to public participation
Putra et al [42]	2021	Authorization, Trust, Access control, Reputation	Yes	No	Reputed, trusted and decentralized Blockchain access control solution for IoT
Weerapanpisit [43]	2022	Reputation system, Geocoding, Spatial computation	No	Yes	Reputation management in cloud-fog-edge using Blockchain
Singh [44]	2022	Security, Privacy, Scalability	No	Yes	Privacy preservation in healthcare using Blockchain and federated learning
Biswas [15]	2019	Load distribution, Scalability, Block weight reduction	No	No	Load distribution in peer-to-peer network to speed-up transaction processing
Jayabalan [17]	2022	Authentication, Encryption, IPFS, Scalability, Privacy	No	No	Address scalability issues in Blockchain healthcare using IPFS

transaction verification, and validations. To track, locate, and reach patients to the closest hospital possible, researchers used geospatial web feature services. The first step is for all patients who require medical services to register with the framework using the decentralized application and the appropriate identity documentation. Once their credentials have been verified using the preloaded smart contract and their registration has been accepted, the patient is regarded as a genuine user who can connect to this framework through their credentials. An automated smart contract run during the login procedure compels the user to adhere to all pre-determined norms and conditions and verifies the device's trustworthiness and authenticity. Through the Dapps, all healthcare users, including doctors, nurses, lab technicians, insurance providers, pathologists, and other medical staff, are connected to healthcare organizations. When a patient needs medical care from a specific hospital, he should log in to the Blockchain network and connect to the doctor of that organization using the credentials he provided when registering in the Dapps. The doctor can then access the patient's specific health information from the Blockchain network using the Identity he has provided. The doctor can offer medical treatments based on the patient's current health status and the diagnosis report accessible through the Blockchain network. According to how severe their disease is, patients for this framework are divided into normal and critical patients, as shown in Fig. 1. In this architecture, novel priority queuing models, specifically high-priority and low-priority, are employed to serve patients based on the patient's state of health. With Blockchain-enabled IoT healthcare systems, the queue implementation is intended to handle access management and scalability challenges while delivering real-time patient monitoring and patient care services. Once a patient is connected to the system, he or she can use the Dapp to search and locate the closest best healthcare professionals and departments for their specific ailment. High-priority patients are treated before low-priority patients. Depending on their chosen healthcare option, the patient will have access to the geospatial mapping service. The closest and most appropriate hospitals to the patient's location are listed along with their map, address, travel time, traffic situation, and distance using the geospatial web feature service. The geospatial web feature Services map, which depicts all the information about the hospital in the Indian city of Bhubaneswar, is shown in Fig. 2. The users who will benefit the most from this geospatial web feature service to locate and access patient care services from a healthcare organization are those who are critically ill, new to the city, have limited knowledge about the healthcare providers, or patients who are unfamiliar with the city's various locations and where time is crucial to saving a patient's life. This framework can also help with remote patient locating, tracking, monitoring, and providing geographically aware patient care services. This will reduce the need for patients to move around physically, the time it takes to receive care, the hospital traffic, and patient travel expenses. Normal patients receive less attention under this framework because they can avail of either in-person or remote patient monitoring services. All transactions entered into a Blockchain network's block are secure, transparent, immutable, interoperable, distributed, and trustworthy since patient health information is extremely sensitive. In their proposed framework, researchers have used cloud storage to accommodate large-scale device connections and the high volume of patient data gathering, processing, transacting, and storing in the healthcare industry.

IV. SYSTEM MODEL

Patient queues are predominant in healthcare, and wait time is one criterion of the approach to care [45]. We exemplify queueing models as an analytical tool that has allowed health service providers to get insights when planning state-of-the-art service systems and handling existing ones. It helps us measure the suitable service capacity to satisfy the patient's needs and balance system utilization and wait time [46]. We consider vital components impacting the patient's wait time and cost: average patient need and service rate. Healthcare services are under immense pressure to render a better quality of attention to more patients while dealing with limited resources.

We can improve the patient healthcare system by the following:

- To manage appointments, arrivals, and queues for the patient.
- To reduce the number of patients in the lobby or waiting room by implementing a perfect queueing system with counters.
- To enhance the patient experience and staff satisfaction in the healthcare system with limited funds and resources.
- To quantify the suitable service to meet the patient's needs, balance the patient's wait time and system utilization.

Algorithm 1 Accessing Geospatial Healthcare Service Using *BCGeo* Framework

Input: User credentials, Service Request
Output: Patient healthcare service

```
for all user wants to connect the framework do
  if (User == new) then
    Register to the framework
  else if (User == Registered User) then
    for all Registered users service request do
      Use user credentials to login into the system
      Smart contract execution == True
      if (user == patient) then
        Priority Checked == True
      end if
      if (patient == Normal patient) then
        The Priority set is low
        Enter into normal patient Queue
        Access the service based on priority
      else if (Patient == Critical Patient) then
        The priority set is high
        Enter into the critical patient queue
        Access the service based on priority
      end if
    end for
  else if (User == Doctor || Pathologist || Nurse) then
    Directly connect to the Blockchain network
  end if
  for all patients service request do
    Select the healthcare department
    if (Department == available Department hospitals) then
      Get the Geospatial maps of all the available hospitals
      Choose the hospital for healthcare service
      Connect to the healthcare personnel's
      Get the Healthcare service
    end if
  end for
end for
```

Here, we consider a queueing network as a bunch of hospital healthcare settings for standard and critical patients, each consisting of multiple service counters, see Fig. 1 There are two types of arrivals: standard and critical patients. Assume a healthcare system where external patients arrivals to either admission or the emergency department. The admission counters have an official who processes patients to clinical wards. In the clinic, patients get consulting services from doctors. Usually, 25% of the patients going by the clinic must return for another checkup in 15 days. Around 10% are admitted for treatment to the hospital; the rest may be discharged. In the emergency ward, around 50% of patients are admitted to the hospital, whereas after treatment, the rest go home. In the healthcare system,

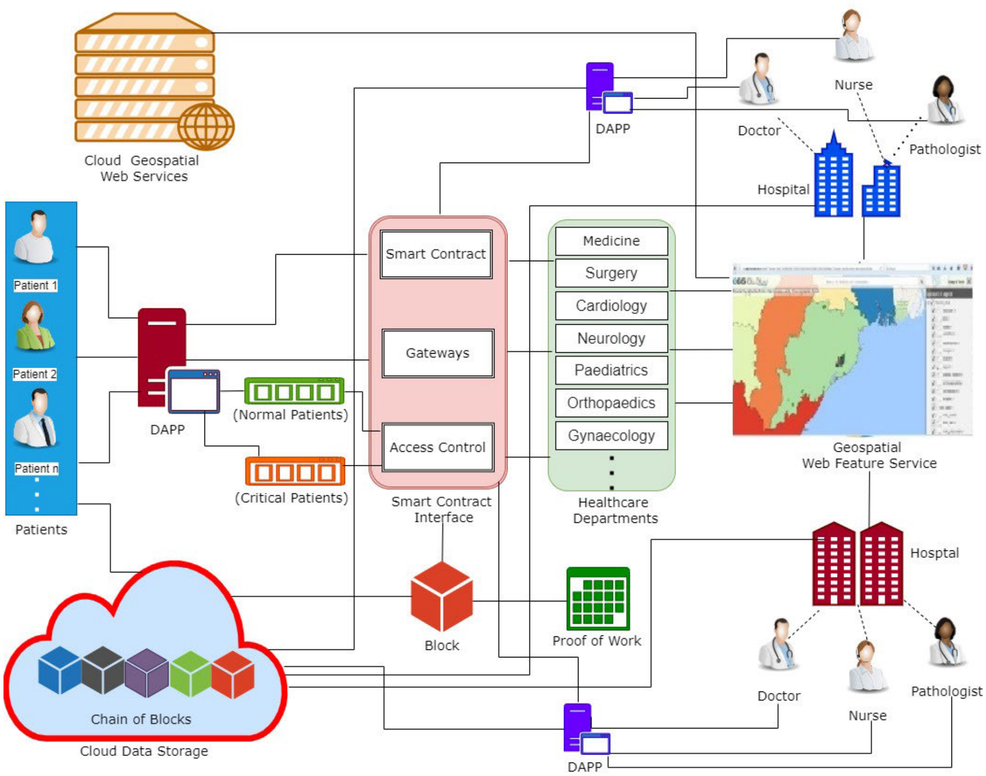

FIGURE 1. ***BCGeo*: Proposed Blockchain assisted geospatial web service framework.**

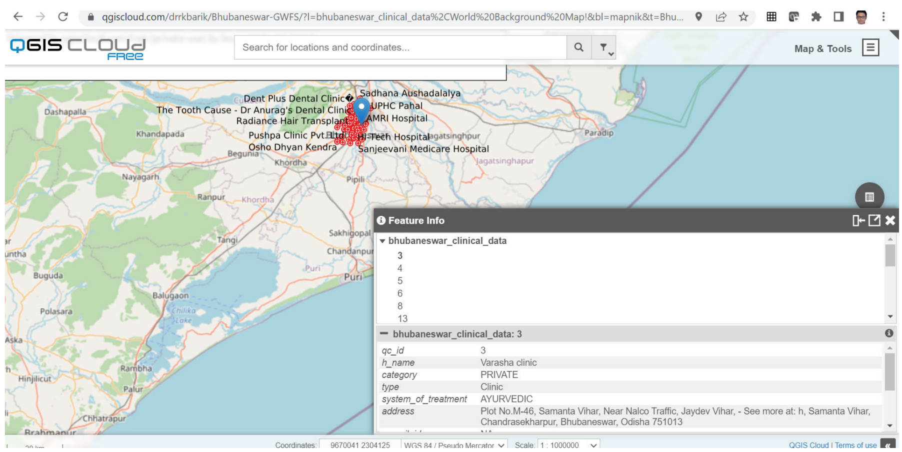

FIGURE 2. **Geospatial web feature services for detailed information on the hospital in Bhubaneswar, India.**

around 75% are given an appointment again for examination in 15 days. To ensure the stability of the queueing network, we must define the number of doctors and the number of hospital beds.

Here, we consider a healthcare servicing framework that consists of n clinics indexed $1, 2, \ldots, n$. The ith clinic may receive patients from external and inside the network. The patient from outside the network into clinic ℓ forms a Poisson process with the rate λ_ℓ. After completion of patient processing at clinic i, the patient is routed to clinic j with probability r_{ij} or exits the clinic with probability $r_{i0} = 1 - \sum_{j=1}^{n} r_{ij}$. The matrix $R = [r_{ij}]_{n \times n}$ is called the routing matrix. It has a broad range of applications and is generally employed to evaluate the performance of various systems, see [47], [48], [49].

Let λ_ℓ denote the arrival rate of patients at the ℓth clinic. Some incoming patients are external, and some arrive from other clinics, including clinic i. Thus, λ_ℓ is the total average number of patients arriving into (and leaving) node i per unit of time. On average, λ_j patients leave clinic j per unit of

TABLE 2. Table of notations.

Notations	Descriptions
IoT	Internet of Things
BC	Blockchain
POW	Proof of Work
IPFS	Interplanetary file system
EHR	Electronic health record
GIS	Geographic Information System
PPGIS	public participatory geographic information system
IoMT	Internet of Medical Things
Dapp	Decentralized applications
QGIS	Quantum geographic information system
QoS	quality of service
DLT	Decentralized ledger technology
HIE	health information exchange
EMR	Electronic medical records
Λ_ℓ	arrival rate of the patient from outside the network
λ_ℓ	total average number of patients
$\mu_\ell(k)$	service rate
m_ℓ	identical doctors at clinic
$\pi(k_\ell)$	probability that there are k_ℓ patients
L_ℓ	average number of patients
W_ℓ	expected time a patient spends at clinic
R_ℓ	average time of the arrival of a patient and its leaving
T_ℓ	total average processing time
ρ_ℓ	average amount of load

time; of these, a fraction r_{ji} go to clinic ℓ. Therefore, the rate of traffic from clinic j to clinic i is $\lambda_j r_{ji}, j = 1, 2, \ldots, n$. Therefore,

$$\lambda_i = \lambda_i + \sum_{j=1}^{n} \lambda_j r_{ji}, \quad i = 1, 2, \ldots, n. \tag{1}$$

The Eq. (1) constitute a set of linear equations, from which we can find λ_i. There are m_ℓ identical doctors at clinic ℓ which follows an exponential distribution, the servicing rate is

$$\mu_\ell(k) = \begin{cases} k\mu_\ell, & k = 1, 2, \ldots, m_\ell, \\ m_\ell \mu_\ell, & k = m_\ell + 1, m_\ell + 2, \ldots \end{cases}$$

Now, it obtains the steady-state probability distribution of a hospital framework network. Let $(k_1, k_2, \ldots, k_n)$ denote the state of the healthcare framework in which there are k_ℓ patients at clinic ℓ in a Jackson network of Markovian queues and let $\pi(k_1, k_2, \ldots, k_n)$ be the steady-state probability that the state of the system is $(k_1, k_2, \ldots, k_n)$. Assume that $\rho_\ell = \frac{\lambda_\ell}{m_\ell \mu_\ell} < 1$, $\ell = 1, 2, \ldots, n$, that is, the load at clinic. Let $\pi(k_\ell)$ be the probability that there are k_ℓ patients at clinic ℓ in an isolated $M/M/m_\ell$ queue. Here for each of the m_ℓ clinics the arrival rate and processing rate are λ_ℓ and μ_ℓ, respectively. Then

$$\begin{aligned} \pi_\ell(k) &= \pi_\ell(0) \frac{\lambda_\ell^k}{k!\mu_\ell^k}, \quad k = 0, 1, \ldots, m_\ell, \\ &= \pi_\ell(0) \frac{\lambda_\ell^k}{m_\ell! m_\ell^{k-m_\ell} \mu_\ell^k}, \quad k = m_\ell + 1, m_\ell + 2, \ldots, \end{aligned} \tag{2}$$

Using normalization condition $\sum_{k=0}^{\infty} \pi_\ell(k) = 1$ and using (2), we obtain only unknown $\pi_\ell(0)$ as

$$\pi_\ell(0) = \left[\sum_{k=0}^{m_\ell - 1} \frac{\lambda_\ell^k}{k!\mu_\ell^k} + \frac{k_\ell^{k_\ell} \rho_\ell^{m_\ell}}{m_\ell!(1-\rho_\ell)} \right]^{-1}. \tag{3}$$

Then from Jackson theorem, we have

$$\pi_\ell(k_1, k_2, \ldots, k_n) = \pi(k_1)\pi(k_2)\ldots\pi(k_n) = \prod_{\ell=1}^{n} \pi_\ell(k_\ell). \tag{4}$$

V. PERFORMANCE MEASURES

The various performance measures of the presented healthcare system can be given as follows:

The average number of patients at clinic ℓ, L_ℓ, is given by

$$L_\ell = \frac{\rho_\ell}{1-\rho_\ell}, \quad \ell = 1, 2, \ldots, n. \tag{5}$$

The total average number of patients in the healthcare system, L_s, is the sum of the averages over all clinics:

$$L_s = \sum_{\ell=1}^{n} L_\ell = \sum_{\ell=1}^{n} \frac{\rho_\ell}{1-\rho_\ell}. \tag{6}$$

Let W_s be the expected sojourn/cycle time that a patient spends in the healthcare system, that is, the expected time interval between the arrival of a patient externally and its departure to the outside. Using Little's law to the entire system and applying (6), we get, and from Little's law, one can derive the average sojourn/cycle time in the healthcare system for each patient as:

$$W_s = \frac{L_s}{\sum_{\ell=1}^{n} \lambda_\ell} \tag{7}$$

Let W_ℓ be the expected time a patient spends at clinic ℓ on each visit to that clinic. Using (5), we have

$$W_\ell = \frac{1}{\mu_\ell(1-\rho_\ell)}, \quad \ell = 1, 2, \ldots, n. \tag{8}$$

Let us consider the average time, R_ℓ, between the arrival of a patient at clinic ℓ and its consequent leaving from the healthcare system. It does not count whether the patient came to clinic ℓ from the outside or from another clinic because of the memoryless routing. The patient goes through clinic ℓ, which takes W_ℓ on average. If it next goes to clinic j with probability $r_{\ell j}$, its average unfinished sojourn time will be R_j. Thus, by applying (8), we may express a set of linear equations

$$R_\ell = W_\ell + \sum_{j=1}^{n} r_{\ell j} R_j \tag{9}$$

Equation (9) finds out R_ℓ uniquely. Every time a patient goes to clinic ℓ, it needs, on average, an amount of processing equal to $1/\mu_\ell$. The total average processing time, T_ℓ, that a patient needs from clinic ℓ throughout its stay in the healthcare system is therefore equal to

$$T_\ell = \frac{\rho_\ell}{\lambda}, \quad \ell = 1, 2, \ldots, n. \tag{10}$$

The ρ_ℓ can be constituted as the average amount of load intended to clinic ℓ that joins the healthcare system externally per unit of time. Correspondingly, the total average time, B_ℓ, that a request passes at clinic ℓ during its life in the healthcare system may be found by using (10) as

$$B_\ell = \frac{T_\ell}{1-\rho_\ell}, \quad \ell = 1, 2, \ldots, n. \tag{11}$$

We minimize the average processing time of a request through the queueing network, with a given budget of K dollar as a constraint. Let us assume that the service rate μ_i can be selected without obstruction except for the constraint $\sum_{i=1}^{n} \mu_i = K$. Further, we assumed that the service times of a request at consecutive nodes are independent. The capacity allocation problem is given by

$$\begin{aligned} \text{Minimize} \quad & Z = \sum_{\ell=1}^{n} \frac{\rho_\ell}{1-\rho_\ell} \\ \text{subject to} \quad & \sum_{\ell=1}^{n} \mu_\ell = K \\ & 0 \leq \mu_\ell \leq \mu. \end{aligned} \tag{12}$$

We can solve the above optimization problem (12) using Langrange multiplier.

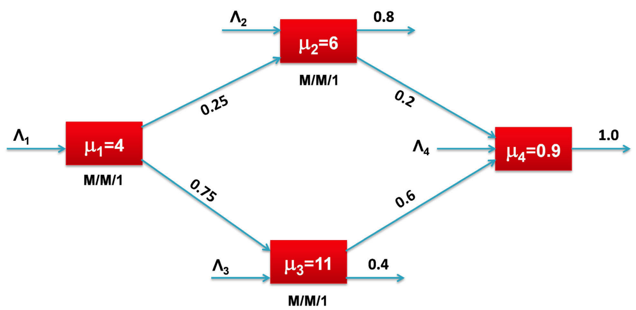

FIGURE 3. Four-node healthcare queueing network system.

VI. NUMERICAL EXAMPLES

We consider the healthcare system having four clinics, each with one doctor, which is depicted in Fig. 3. We find the performance measures of the healthcare system in each clinic as well as the total system. Also, we optimize the doctors' processing rates μ_i^* and relate them. Route matrix $Q = \begin{pmatrix} 0 & 0.25 & 0.75 & 0 \\ 0 & 0 & 0 & 0.2 \\ 0 & 0 & 0 & 0.6 \\ 0 & 0 & 0 & 0 \end{pmatrix}$, external patient arrival rates: $\lambda = \{2, 1, 0.5, 0.3\}$, processing rates: $\mu = \{16, 17, 18, 19, 20\}$ and $\lambda = \{4.785714, 5.785714, 3.392857, 4.0714285\}$.

Here we compare the typical healthcare system with an optimized healthcare system where we optimize the service

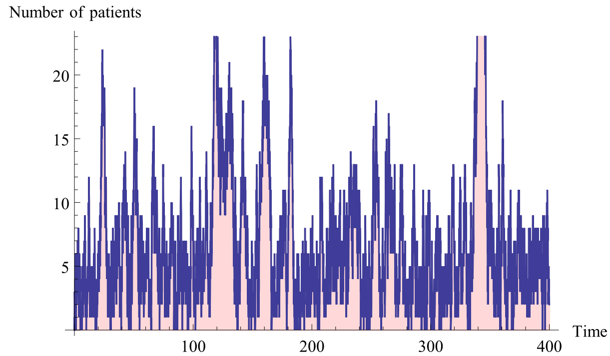

FIGURE 4. Sample path when c = 4.

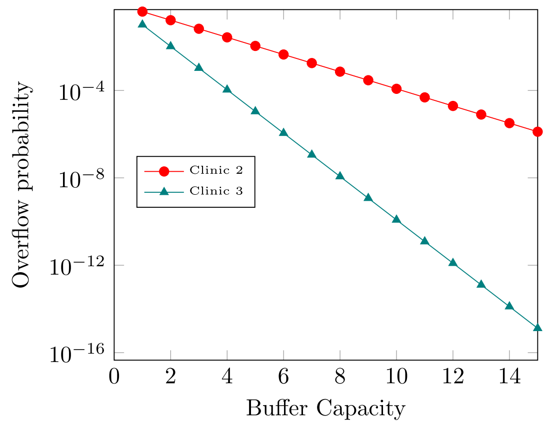

FIGURE 5. Buffer space versus overflow probability.

rates. In the first part of Table 3, the performance indices of the typical healthcare system are provided. One may observe from the table that the total average number of patients in the healthcare system and the expected sojourn/cycle time a patient spends in the healthcare system decrease as the number of clinics increases. We optimize the service rates using equation (12) where we use the bound of $C = 90$ and achieve an optimal processing rate vector of $\mu^* = \{8.925, 8.425, 8.925, 8.725\}$. The second part of the table is given using optimized μ^* value. We observe a substantial enhancement in all the performance measures in the healthcare system with an optimized service rate.

Here we study a simulation of the healthcare system with four doctors and an infinite waiting space system over time. We see how dynamic this process is, as exemplified in Fig. 4. The y-axis is the number of patients in the healthcare system, and the x-axis is time. In this sample path, $\lambda = 12$, $\mu = 3.5$, $t = 400$ periods. Thus, there is a significantly fluctuating variability of the number of patients within the healthcare system because of the high utilization $\rho = 0.857$. The process is indeed empty, but the periods are lengthy and full. That reflects the nature of a lineup of patients in the system. Fig. 5 depicts the impact of buffer size on overflow probability. The overflow probability decreases as the buffer size increases. With the increase in the number of clinics for fixed buffer size, the overflow probability decreases.

Table 4 illustrates performance indices of three clinics with multiple doctors, see Fig. 6. The several parameters

TABLE 3. Performance measures of five node system with multiple servers.

Five node system with single server

	$\mu_1 = 4, \mu_2 = 6, \mu_3 = 11, \mu_4 = 9.9$						
i	P_0	P_c	L_q	L_s	W_q	W_s	$\hat{D}$
1	0.500000	0.500000	0.500000	1.00000	0.250000	0.500000	0.250000
2	0.250000	0.750002	0.0833333	0.333333	0.0555555	0.222222	0.166667
3	0.181818	0.818183	0.0404038	0.222222	0.0202019	0.111111	0.0909090
4	0.181818	0.818183	0.0404038	0.222223	0.0224466	0.123457	0.101010
	TS= 1.950, $E(I) = 0.2052$, Sojourn time= 0.1300						
	$\mu_1^* = 8.925, \mu_2^* = 8.425, \mu_3^* = 8.925, \mu_4^* = 8.725$						
i	P_0	P_c	L_q	L_s	W_q	W_s	$\hat{D}$
1	0.224090	0.775910	0.0647194	0.288810	0.0323597	0.144405	0.112045
2	0.178042	0.821956	0.0385652	0.216606	0.0257101	0.144404	0.118695
3	0.224090	0.775910	0.0647194	0.288810	0.0323597	0.144405	0.112045
4	0.206304	0.793701	0.0536246	0.259927	0.0297914	0.144404	0.114613
	TS= 1.05415, $E(I) = 0.392761$, Sojourn time= 0.277408						

TABLE 4. Performance measures of the healthcare system with three clinics and multiple doctors.

Three clinics in the healthcare system with multiple servers

	$\Lambda_1 = 15, \Lambda_2 = 5, \Lambda_3 = 0, \mu_1 = 45, \mu_2 = 10, \mu_3 = 3$					
	$m_1 = 1, m_2 = 3, m_3 = 7$			$m_1 = 1, m_2 = 5, m_3 = 7$		
λ_ℓ	15.00000	11.83487	8.48670	15.00000	11.83487	8.48670
ρ_ℓ	33.33%	39.45%	40.41%	33.33%	23.67%	40.41%
L_ℓ	0.500000	1.272487	2.848186	0.500000	1.185893	2.848186
$L_{q\ell}$	0.166667	0.08900	0.019287	0.166667	0.002406	0.019287
W_ℓ	0.033333	0.10752	0.335606	0.033333	0.100203	0.335606
$W_{q\ell}$	0.011111	0.00752	0.002273	0.011111	0.000203	0.002273

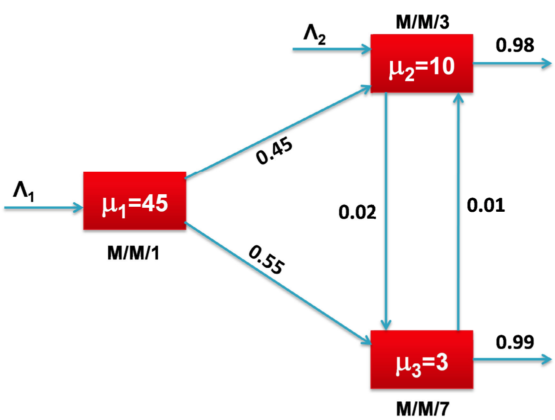

FIGURE 6. Three-node healthcare system.

are assumed as: Route matrix $Q = \begin{pmatrix} 0 & 0.45 & 0.55 \\ 0 & 0 & 0.02 \\ 0 & 0.01 & 0 \end{pmatrix}$, $\lambda = (15, 5, 0)$, and $\mu_1 = 45$, $\mu_2 = 10$, $\mu_3 = 3$.

Here we consider the first clinic consists of one fixed doctor and various doctors in other clinics. Varying the number of doctors in Clinic 2, we note that the average wait time in the queue and the system decreases with the number of doctors.

Fig. 7 presents the impact of several patients versus marginal probabilities for several clinics. Note that the marginal probabilities decrease with an increase in the number of patients; for many patients, the probabilities are almost negligible. The number of patients waiting times reduces with the increase of clinics. Fig. 8 depicts the total average number of patients versus probability. As the number of patients increases, the probability increases and finally attains its minimum value.

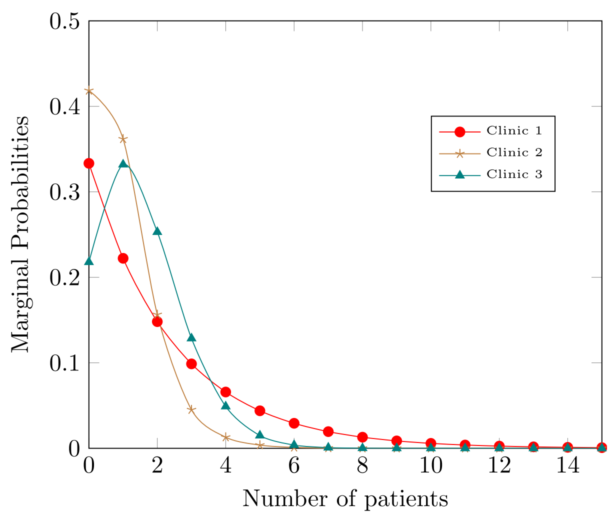

FIGURE 7. Number of patients versus marginal probabilities.

TABLE 5. Comparison of the proposed model with the current healthcare systems.

Research Works	*Decentralization*	*Immutability*	*Patient Priority*	*Access Control*	*Confidentiality*	*Geospatial Mapping*
Azbeg et al.[34], 2022	✓	✓	×	✓	✓	×
Boulos et al. [11], 2018	✓	✓	×	×	×	✓
Xiang et al.[36], 2022	✓	✓	×	✓	✓	×
Sun et al.[50], 2021	×	×	×	×	✓	×
Singh et al.[44], 2022	✓	✓	×	✓	✓	×
Mani et al.[22], 2021	✓	✓	×	✓	✓	×
Tan et al.[12], 2021	✓	✓	×	×	✓	×
Sun et al.[16], 2020	✓	✓	×	✓	✓	×
Jayabalan et al.[17], 2022	✓	✓	×	✓	✓	×
Mehbodniya et al.[23], 2021	✓	✓	×	×	✓	×
Proposed System	✓	✓	✓	✓	✓	✓

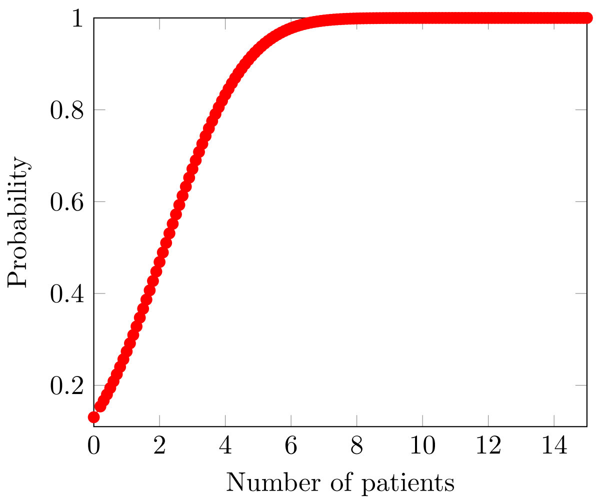

FIGURE 8. Number of patients versus probability.

VII. FINDINGS AND DISCUSSION

This section shows the proposed framework's findings compared to existing frameworks to ensure the offered solution's effectiveness, quality, and practicality in healthcare domains. All transactions made on a Blockchain ledger in healthcare systems are guaranteed to be irreversible, tamper-proof, and permanent by the immutability feature of Blockchain. The immutability attribute of Blockchain transactions enables them to be efficient, trustworthy, honest, and transparent. Scalable Blockchain networks for the healthcare sector can manage numerous device connections, massive data collections, increasing transactions, and processing without system failure. This proposed system, which combines geospatial mapping with Blockchain technology, has the potential to transform healthcare organizations by improving patient care, enabling more accurate and efficient data sharing, and enhancing care coordination. Geospatial mapping assists healthcare organizations in better identifying patient populations, identifying areas of need, and developing targeted therapies. It can improve patient outcomes by allowing healthcare professionals to access and share patient information more precisely, accurately, and quickly. Healthcare providers may ensure that all users have access to the same information by securely storing and sharing patient health records using Blockchain technology, regardless of where the patient is situated. This can assist in improving patient care coordination and reducing the risk of errors or omissions in patient care. The geospatial web service features in the healthcare industry can trace, track, and locate a patient's present status and geographic location to provide healthcare services. It also makes it possible to precisely map the spatiotemporal location of medical facilities and find the accessibility of nearby hospitals. Blockchain ensures patient data's confidentiality and integrity while giving patients more control over their data. Queuing prioritizes patients based on their importance or criticality. High-priority or urgent cases may be prioritized above patients with common illnesses. Prioritizing patients enables the network to process high-priority patients faster, increasing overall throughput and scalability. A queueing mechanism handles transactions more effectively, reducing processing time and enhancing the Blockchain's overall throughput. This strategy also helps to reduce the overhead on specific network nodes, boosting scalability even more. A patient's life may be saved through priority-based care since critically ill patients are given higher priority than others. The availability, auditability, stability, and prevention of system failure are all guaranteed by decentralization technology in healthcare systems.

The assessment metric is based on the technological characteristics of immutability, scalability, geospatial mapping, patient priority, and decentralization of the proposed healthcare systems. Table 5 compares the proposed framework with some previously proposed healthcare system solutions.

VIII. CONCLUSION

In recent days, Blockchain-integrated IoT healthcare systems have automated the process of gathering, transacting, accessing, viewing, visualizing, verifying, updating, and storing healthcare data in a decentralized and distributed architecture. ***BCGeo***, a Blockchain-enabled healthcare Internet of Things framework with geographic support has been proposed for healthcare organizations. This Blockchain-based Geospatial Web Services architecture enables enhanced data processing, visualizing, analyzing, storing, and transactional capabilities in addition to secure, private, reliable, immutable, and transparent management of confidential healthcare data. The information about the hospitals in the Indian city of Bhubaneswar is visualized on a map using the free and open-source QGIS cloud platform in this work. A novel queueing model is included in this proposed framework to address the access management and scalability challenges and deliver real-time patient care service. For prioritizing patient care service to critically ill patients, the proposed healthcare framework deploys a low-priority queue for regular patients and a high-priority queue for critically ill patients.

In addition, it explains the performance analysis of ***BCGeo***. It carries the performance measurement, experimental findings on the suggested architecture, and graphs displaying the various possible outputs of arithmetic simulations. Moreover, it brings the proposed architecture's performance measurement and empirical findings. Future work on this framework aims to employ a more efficient queueing technique to quickly provide patients with the finest healthcare. Moreover, compared to previously existing healthcare models, our proposed framework efficiently provides immutability, scalability, geospatial mapping, patient prioritization, and decentralization of privacy preservation policies. It is also planned to use the techniques described in this research to analyze and implement them in other cutting-edge application areas, such as smart homes, smart cities, and intelligent wearable technology.

ACKNOWLEDGMENT

The authors gratefully credit the IoT and Cloud Computing Laboratory of IIIT Bhubaneswar for providing computational resources.

REFERENCES

[1] R. K. Lenka, A. K. Rath, and S. Sharma, "Building reliable routing infrastructure for green IoT network," *IEEE Access*, vol. 7, pp. 129892–129909, 2019.

[2] R. K. Lenka, A. K. Rath, Z. Tan, S. Sharma, D. Puthal, N. V. R. Simha, M. Prasad, R. Raja, and S. S. Tripathi, "Building scalable cyber-physical-social networking infrastructure using IoT and low power sensors," *IEEE Access*, vol. 6, pp. 30162–30173, 2018.

[3] A. G. Ghandour, M. Elhoseny, and A. E. Hassanien, "Blockchains for smart cities: A survey," in *Security in Smart Cities: Models, Applications, and Challenges*. Springer, 2019, pp. 193–210.

[4] S. Makani, R. Pittala, E. Alsayed, M. Aloqaily, and Y. Jararweh, "A survey of blockchain applications in sustainable and smart cities," *Cluster Comput.*, vol. 25, no. 6, pp. 3915–3936, 2022.

[5] M. Pincheira, E. Donini, R. Giaffreda, and M. Vecchio, "A blockchain-based approach to enable remote sensing trusted data," in *Proc. IEEE Latin Amer. GRSS ISPRS Remote Sens. Conf. (LAGIRS)*, Mar. 2020, pp. 652–657.

[6] T. Pratik, R. K. Lenka, G. K. Nayak, and A. Kumar, "An architecture to support interoperability in IoT devices," in *Proc. Int. Conf. Adv. Comput., Commun. Control Netw. (ICACCCN)*, Oct. 2018, pp. 705–710.

[7] M. Farnaghi and A. Mansourian, "Blockchain, an enabling technology for transparent and accountable decentralized public participatory GIS," *Cities*, vol. 105, Oct. 2020, Art. no. 102850.

[8] P. K. Sharma and J. H. Park, "Blockchain based hybrid network architecture for the smart city," *Future Gener. Comput. Syst.*, vol. 86, pp. 650–655, Sep. 2018.

[9] S. R. Mallick and S. Sharma, "EMRI: A scalable and secure blockchain-based IoMT framework for healthcare data transaction," in *Proc. 19th OITS Int. Conf. Inf. Technol. (OCIT)*, Dec. 2021, pp. 261–266.

[10] P. Zhang and M. N. K. Boulos, "Blockchain solutions for healthcare," in *Precision Medicine for Investigators, Practitioners and Providers*. Amsterdam, The Netherlands: Elsevier, 2020, pp. 519–524.

[11] M. N. K. Boulos, J. T. Wilson, and K. A. Clauson, "Geospatial blockchain: Promises, challenges, and scenarios in health and healthcare," *Int. J. Health Geograph.*, vol. 17, pp. 1–10, Jul. 2018.

[12] L. Tan, K. Yu, N. Shi, C. Yang, W. Wei, and H. Lu, "Towards secure and privacy-preserving data sharing for COVID-19 medical records: A blockchain-empowered approach," *IEEE Trans. Netw. Sci. Eng.*, vol. 9, no. 1, pp. 271–281, Jan./Feb. 2022.

[13] P. Zhang and M. Zhou, "Security and trust in blockchains: Architecture, key technologies, and open issues," *IEEE Trans. Computat. Social Syst.*, vol. 7, no. 3, pp. 790–801, Jun. 2020.

[14] X. Liu, Z. Wang, C. Jin, F. Li, and G. Li, "A blockchain-based medical data sharing and protection scheme," *IEEE Access*, vol. 7, pp. 118943–118953, 2019.

[15] S. Biswas, K. Sharif, F. Li, B. Nour, and Y. Wang, "A scalable blockchain framework for secure transactions in IoT," *IEEE Internet Things J.*, vol. 6, no. 3, pp. 4650–4659, Jun. 2019.

[16] J. Sun, X. Yao, S. Wang, and Y. Wu, "Blockchain-based secure storage and access scheme for electronic medical records in IPFS," *IEEE Access*, vol. 8, pp. 59389–59401, 2020.

[17] J. Jayabalan and N. Jeyanthi, "Scalable blockchain model using off-chain IPFS storage for healthcare data security and privacy," *J. Parallel Distrib. Comput.*, vol. 164, pp. 152–167, Jun. 2022.

[18] Y.-P. Lin, H. Mukhtar, K.-T. Huang, J. R. Petway, C.-M. Lin, C.-F. Chou, and S.-W. Liao, "Real-time identification of irrigation water pollution sources and pathways with a wireless sensor network and blockchain framework," *Sensors*, vol. 20, no. 13, p. 3634, Jun. 2020.

[19] N. Alrebdi, A. Alabdulatif, C. Iwendi, and Z. Lian, "SVBE: Searchable and verifiable blockchain-based electronic medical records system," *Sci. Rep.*, vol. 12, no. 1, p. 266, Jan. 2022.

[20] K. Azbeg, O. Ouchetto, and S. J. Andaloussi, "BlockMedCare: A healthcare system based on IoT, blockchain and IPFS for data management security," *Egyptian Informat. J.*, vol. 23, no. 2, pp. 329–343, Jul. 2022.

[21] Z. Sun, D. Han, D. Li, X. Wang, C.-C. Chang, and Z. Wu, "A blockchain-based secure storage scheme for medical information," *EURASIP J. Wireless Commun. Netw.*, vol. 2022, no. 1, p. 40, Dec. 2022.

[22] V. Mani, P. Manickam, Y. Alotaibi, S. Alghamdi, and O. I. Khalaf, "Hyperledger healthchain: Patient-centric IPFS-based storage of health records," *Electronics*, vol. 10, no. 23, p. 3003, Dec. 2021.

[23] A. Mehbodniya, R. Neware, S. Vyas, M. R. Kumar, P. Ngulube, and S. Ray, "Blockchain and IPFS integrated framework in bilevel fog-cloud network for security and privacy of IoMT devices," *Comput. Math. Methods Med.*, vol. 2021, Dec. 2021, Art. no. 7727685.

[24] R. Kumar, R. Tripathi, N. Marchang, G. Srivastava, T. R. Gadekallu, and N. N. Xiong, "A secured distributed detection system based on IPFS and blockchain for industrial image and video data security," *J. Parallel Distrib. Comput.*, vol. 152, pp. 128–143, Jun. 2021.

[25] L. Zhang, W. Zeng, Z. Jin, Y. Su, and H. Chen, "A research on traceability technology of agricultural products supply chain based on blockchain and IPFS," *Secur. Commun. Netw.*, vol. 2021, Nov. 2021, Art. no. 3298514.

[26] S. El Kafhali and K. Salah, "Efficient and dynamic scaling of fog nodes for IoT devices," *J. Supercomput.*, vol. 73, no. 12, pp. 5261–5284, Dec. 2017.

[27] S. Agrawal and R. D. Gupta, "Web GIS and its architecture: A review," *Arabian J. Geosci.*, vol. 10, no. 23, pp. 1–13, Dec. 2017.

[28] W. Han, Z. Yang, L. Di, B. Zhang, and C. Peng, "Enhancing agricultural geospatial data dissemination and applications using geospatial web services," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 7, no. 11, pp. 4539–4547, Nov. 2014.

[29] M. O. Mete and T. Yomralioglu, "Implementation of serverless cloud GIS platform for land valuation," *Int. J. Digit. Earth*, vol. 14, no. 7, pp. 836–850, Jul. 2021.

[30] S. Grasso, P. Claps, D. Ganora, and A. Libertino, "A web-based open-source geoinformation tool for regional water resources assessment," *Water Resour. Manage.*, vol. 35, no. 2, pp. 675–687, Jan. 2021.

[31] J. Wagemann, O. Clements, R. M. Figuera, A. P. Rossi, and S. Mantovani, "Geospatial web services pave new ways for server-based on-demand access and processing of Big Earth Data," *Int. J. Digit. Earth*, vol. 11, no. 1, pp. 7–25, Jan. 2018.

[32] A. Roehrs, C. A. da Costa, R. da Rosa Righi, V. F. da Silva, J. R. Goldim, and D. C. Schmidt, "Analyzing the performance of a blockchain-based personal health record implementation," *J. Biomed. Informat.*, vol. 92, Apr. 2019, Art. no. 103140.

[33] Y. Zhang, B. Li, B. Liu, J. Wu, Y. Wang, and X. Yang, "An attribute-based collaborative access control scheme using blockchain for IoT devices," *Electronics*, vol. 9, no. 2, p. 285, Feb. 2020.

[34] K. Azbeg, O. Ouchetto, and S. J. Andaloussi, "Access control and privacy-preserving blockchain-based system for diseases management," *IEEE Trans. Computat. Social Syst.*, early access, Jul. 8, 2022, doi: 10.1109/TCSS.2022.3186945.
[35] B. S. Egala, A. K. Pradhan, V. Badarla, and S. P. Mohanty, "Fortified-chain: A blockchain-based framework for security and privacy-assured Internet of Medical Things with effective access control," *IEEE Internet Things J.*, vol. 8, no. 14, pp. 11717–11731, Jul. 2021.
[36] X. Xiang, J. Cao, and W. Fan, "Decentralized authentication and access control protocol for blockchain-based e-health systems," *J. Netw. Comput. Appl.*, vol. 207, Nov. 2022, Art. no. 103512.
[37] S. K. Rana, S. K. Rana, K. Nisar, A. A. Ag Ibrahim, A. K. Rana, N. Goyal, and P. Chawla, "Blockchain technology and artificial intelligence based decentralized access control model to enable secure interoperability for healthcare," *Sustainability*, vol. 14, no. 15, p. 9471, Aug. 2022.
[38] T. Frikha, A. Chaari, F. Chaabane, O. Cheikhrouhou, and A. Zaguia, "Healthcare and fitness data management using the IoT-based blockchain platform," *J. Healthcare Eng.*, vol. 2021, Jul. 2021, Art. no. 9978863.
[39] P. Shi, H. Wang, S. Yang, C. Chen, and W. Yang, "Blockchain-based trusted data sharing among trusted stakeholders in IoT," *Softw., Pract. Exp.*, vol. 51, no. 10, pp. 2051–2064, Oct. 2021.
[40] Z. Wan, W. Liu, and H. Cui, "HIBEChain: A hierarchical identity-based blockchain system for large-scale IoT," *IEEE Trans. Depend. Sec. Comput.*, vol. 20, no. 2, pp. 1286–1301, Mar. 2023.
[41] W. Yan, N. Zhang, L. L. Njilla, and X. Zhang, "PCBChain: Lightweight reconfigurable blockchain primitives for secure IoT applications," *IEEE Trans. Very Large Scale Integr. (VLSI) Syst.*, vol. 28, no. 10, pp. 2196–2209, Oct. 2020.
[42] G. D. Putra, V. Dedeoglu, S. S. Kanhere, R. Jurdak, and A. Ignjatovic, "Trust-based blockchain authorization for IoT," *IEEE Trans. Netw. Service Manage.*, vol. 18, no. 2, pp. 1646–1658, Jun. 2021.
[43] P. Weerapanpisit, S. Trilles, J. Huerta, and M. Painho, "A decentralized location-based reputation management system in the IoT using blockchain," *IEEE Internet Things J.*, vol. 9, no. 16, pp. 15100–15115, Aug. 2022.
[44] S. Singh, S. Rathore, O. Alfarraj, A. Tolba, and B. Yoon, "A framework for privacy-preservation of IoT healthcare data using federated learning and blockchain technology," *Future Gener. Comput. Syst.*, vol. 129, pp. 380–388, Apr. 2022.
[45] F. A. Silva, T. A. Nguyen, I. Fé, C. Brito, D. Min, and J. Lee, "Performance evaluation of an Internet of Healthcare Things for medical monitoring using M/M/c/K queuing models," *IEEE Access*, vol. 9, pp. 55271–55283, 2021.
[46] M. Adhikari, M. Mukherjee, and S. N. Srirama, "DPTO: A deadline and priority-aware task offloading in fog computing framework leveraging multilevel feedback queueing," *IEEE Internet Things J.*, vol. 7, no. 7, pp. 5773–5782, Jul. 2020.
[47] J. F. Hayes and T. V. G. Babu, *Modeling and Analysis of Telecommunications Networks*. Hoboken, NJ, USA: Wiley, 2004.
[48] J. F. Shortle, J. M. Thompson, D. Gross, and C. M. Harris, *Fundamentals of Queueing Theory*, vol. 399. Hoboken, NJ, USA: Wiley, 2018.
[49] J. M. Smith, *Introduction to Queueing Networks: Theory ∩ Practice*. Springer, 2018.
[50] Y. Sun, J. Liu, K. Yu, M. Alazab, and K. Lin, "PMRSS: Privacy-preserving medical record searching scheme for intelligent diagnosis in IoT healthcare," *IEEE Trans. Ind. Informat.*, vol. 18, no. 3, pp. 1981–1990, Mar. 2022.

SOUBHAGYA RANJAN MALLICK was born in Odisha, India. He received the master's degree in computer science and engineering from the Biju Patnaik University of Technology, Rourkela, Odisha, in 2012. He is currently pursuing the Ph.D. degree in computer science and engineering with the International Institute of Information Technology Bhubaneswar, Odisha. He is also an Assistant Professor with the Computer Science and Engineering Department, International Institute of Information Technology Bhubaneswar. He has more than 13 years of experience in teaching and research. His research interests include wireless sensor networks, the IoT, blockchain, cryptography, edge computing, fog computing, and cloud computing.

RAKESH K. LENKA is an Assistant Professor with the Department of Computer Science and Engineering, International Institute of Information Technology (IIIT) Bhubaneswar. He has published over 50 research articles in reputed journals and conference proceedings. His research interests include the green IoT, fog/mist computing, model checking, blockchain technology, recommendation systems, geographical information systems, and DFA-based pattern matching. He is a Professional Member of the CSI and the International Association of Engineers (IAENG). He has served as a reviewer for various reputed international journals and conferences.

VEENA GOSWAMI received the Ph.D. degree from Sambalpur University, India. She was a Research Associate with the Indian Institute of Technology, Kharagpur, for two years. She is currently a Professor with the School of Computer Application, KIIT University, Bhubaneswar, India. She has published research articles in INFORMS *Journal on Computing*, *Computers and Operations Research*, RAIRO *Operations Research*, *Computers and Mathematics with Applications*, *Applied Mathematical Modeling*, *Computers and Industrial Engineering*, and *Applied Mathematics and Computation*. Her research interest includes continuous- and discrete-time queues. She is a Life Member of the Indian Society for Technical Education, the Orissa Information Technology Society, the Orissa Mathematical Society, the Indian Science Congress Association, and the Indian Statistical Association.

SURAJ SHARMA (Member, IEEE) is currently an Associate Professor with the Department of Computer Science and Engineering, Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur, India. He has published over 80 research articles in the reputed international journals and conferences. His research interests include the Internet of Things (IoT), blockchain, cyber security, IoV, and cloud and edge computing. He serves on the editorial boards of top quality international journals as the Guest Editor, including the *ACM Transactions on Multimedia Computing Communications and Applications*, *IEEE Consumer Electronics Magazine*, *International Journal of Information System Modeling and Design* (IGI Global), *Recent Advances in Computer Science and Communication* (Bentham Science), and *Computers and Electrical Engineering* (Elsevier). He is an active member of many research communities, including the IEEE Computer Society, ACM, IEI, CSI, and ISRD.

ASISH KUMAR DALAI received the B.Tech. degree from GIET University, Gunupur, India, and the M.Tech. and Ph.D. degrees from NIT Rourkela, India. He is an Assistant Professor with the School of Computer Engineering, VIT-AP University, India. He has more than ten years of teaching and research experience in various engineering colleges and universities. He has published several research articles in various international journals and conferences. His research interests include wireless network security, the IoT, and machine learning. He has served as an organizing chair and the publicity chair for many national and international conferences and a member of technical program committees. He is also associated with various educational and research societies, such as IEEE, ACM, IET, IACSIT, ISTE, UACEE, CSI, IAENG, and ISCA. He has also served on many journals and conferences as an editorial board member or a reviewer.

HIMANSU DAS received the B.Tech. degree from the Institute of Technical Education and Research, Odisha, India, the M.Tech. degree in computer science and engineering from the National Institute of Science and Technology, Odisha, and the Ph.D. degree in engineering from the Veer Surendra Sai University of Technology (VSSUT), Odisha. He is an Associate Professor with the School of Computer Engineering, Kalinga Institute of Industrial Technology (KIIT) Deemed to be University, Bhubaneswar, India. He is proficient in the field of computer science engineering. He has more than 12 years of teaching and research experience in various engineering colleges and universities. He has published several research articles in various international journals and conferences. He has also edited several books published by IGI Global, Springer, CRC Press, and Elsevier. His research interests include data mining, soft computing, and machine learning. He served as an organizing chair, the publicity chair, and a member of the technical program committees of many national and international conferences. He is associated with various educational and research societies, such as IET, IACSIT, ISTE, UACEE, CSI, IAENG, and ISCA. He has also served on many journals and conferences as an editorial board member or a reviewer.

RABINDRA K. BARIK (Member, IEEE) received the M.Tech. and Ph.D. degrees from the Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India, in 2009 and 2014, respectively. He is currently an Associate Professor with the School of Computer Applications, KIIT Deemed to be University, Bhubaneswar, India. He has selected for MHRD Scholarship during his M.Tech. and Ph.D. studies. He has qualified GATE–2007 in information technology conducted by IIT-Kanpur. He is doing collaborative research with The University of Texas at Dallas and the University of Rhode Island in the field of fog computing. He has published more than 30 international journals, such as Springer, Elsevier, and IGI Global. He has also published more than 50 conference papers in various top-level conferences, such as Global-SIP, CHASE, TENCON, and INDICON. He has more than 25 book chapters on his credit. Prior to this, he has edited one book on Springer Nature named as *Cloud Computing for Geospatial Big Data Analytics: Intelligent Edge, Fog and Mist Computing* in the series of studies in big data. His research interests include geospatial data science, geospatial big data infrastructure, geospatial database, geospatial cloud computing, fog computing, and IPR. He is a member of IAENG. He is also served as a TPC and a PC member in many conferences. He has received the Best Paper Awards in FICTA-2020, ICSCC-2017, and ICECE-2017 Conferences. He is ranked among the World's Top 2% Scientists as per the recent study conducted by researchers of ICSR Laboratory, Elsevier, B. V., and Stanford University, USA, in 2022. He has reviewed many journals, such as Springer, Elsevier, IEEE, and IGI Global.