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A Novel Smart Healthcare Design, Simulation, and Implementation Using Healthcare 4.0 Processes

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ABSTRACT Blockchain technology is found to have its applicability in almost every domain because of its advantages such as crypto-security, transparency, immutability, decentralized data network. In present times, a smart healthcare system with a blockchain data network and healthcare 4.0 processes provides transparency, easy and faster accessibility, security, efficiency, etc. Healthcare 4.0 trends include industry 4.0 processes such as the internet of things (IoT), industrial IoT (IIoT), cognitive computing, artificial intelligence, cloud computing, fog computing, edge computing, etc. The goal of this work is to design a smart healthcare system and it is found to be possible through integration and interoperability of Blockchain 3.0 and Healthcare 4.0 in consideration with healthcare ground-realities. Here, healthcare 4.0 processes used for data accessibility are targeted to be validated through statistical simulation-optimization methods and algorithms. The blockchain is implemented in the Ethereum network, and with associated programming languages, tools, and techniques such as solidity, web3.js, Athena, etc. Further, this work prepares a comparative and comprehensive survey of state-of-the-art blockchain-based smart healthcare systems. The comprehensive survey includes methodology, applications, requirements, outcomes, future directions, etc. A list of groups, organizations, and enterprises are prepared that are working in electronic health records (EHR), electronic medical records (EMR) or electronic personal records (EPR) mainly, and a comparative analysis is drawn concerning adopting the blockchain technology in their processes. This work has explored optimization algorithms applicable to Healthcare 4.0 trends and improves the performance of blockchain-based decentralized applications for the smart healthcare system. Further, smart contracts and their designs are prepared for the proposed system to expedite the trust-building and payment systems. This work has considered simulation and implementation to validate the proposed approach. Simulation results show that the Gas value required (indicating block size and expenditure) lies within current Etherum network Gas limits. The proposed system is active because block utilization lies above 80%. Automated smart contract execution is below 20 seconds. A good number (average 3 per simulation time) is generated in the network that indicates a health competition. Although there is error observed in simulation and implementation that lies between 0.55% and 4.24%, these errors are not affecting overall system performance because simulated and actual (taken in state-of-the-art) data variations are negligible.

INDEX TERMS Block, blockchain 3.0, healthcare 4.0, Industrial IoT (IIoT), Industry 4.0, Internet of Things (IoT), mining optimization, smart solution, transaction.

I. INTRODUCTION

Satashi Nakamoto (a pseudonym) in a white paper introduced a peer to peer version of the network without having a central financial institution in between to regulate and record the transaction. This functionality is replaced by the concept of a digital signature to ensure no double-spending problem [1]–[5]. Thus blockchain is a collection of the ledger in the form of a diary which is "impossible" to edit without concern (Term "impossible" refers to numerous attempts

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made to breach the defined process). Blockchain is considered to be more of a concept than a framework. The major blockchain technology properties include peer-to-peer network, public and private ledger, distributed or decentralized approach, immutability, data integrity, transparent ledger, cryptographical security, and provide confidentiality [2]–[8]. Blockchain technology has established itself as the fifth revolutionary computing archetype following mainframe, personal computers, internet, portable devices and social networking ruling the world. Blockchain 1.0 talks about financial transaction or currency, blockchain 2.0 is related to smart contracts in the field of economic, market and other financial areas while blockchain 3.0 is related to applications related to governance, health care, science, literature, supply chain management, and artwork. Blockchain emerged out to resolve major issues such as the removal of the central institution and the double-spending problem. While transacting money/ data from one node to another often an overhead is imposed on participants as ''service charge'' in the form of a fraction of money. Participating nodes not only have to bear any extra cost but also there is a chance of compromising with data accessibility. An attempt to send data under ''unavailable'' status leads to a scenario termed as a double-spending problem. It avoids the re-usability of transactions among multiple participants of a P2P network.

Industry 4.0 revolutionized engineering and manufacturing solutions has provided system automation at a large scale in smart technology applications. Healthcare 4.0 is one of such smart technology applications that uses various industry 4.0 concepts in healthcare [9]–[11]. Healthcare 4.0 includes IoT, IIoT, healthcare, cognitive computing, artificial intelligence, machine learning, virtual reality, augmented reality and cloud computing. An IoT interconnects the local area network in a small geographical region (For example, a single doctor to multiple patient records, records of a hospital, etc.) whereas, IIoT helps to interconnect devices at a larger scale (For example, inter-connection of hospitals within a city or across cities, the interconnection of doctors with the same or different specialization across a larger region, etc.). Data collected through IoT or IIoT networks is stored at cloud using cloud computing concepts. Data over the cloud is analyzed for a smart healthcare system using cognitive computing and artificial intelligence concepts.

Blockchain technology has various applications in the healthcare system [12]–[15]. Blockchain is distributed in nature and because of this peculiar characteristic removal of central governing bodies at the global scale needs an entirely different framework and operationality in areas. It is acceptable to consider that the functionality of blockchain won't be easily accepted by society who is in practice to be under cover of traditional controlling/ governing bodies which they consider to be ''trustworthy''. This is true for every technology during its initial expansion in the ongoing computing era that mainstream is a little reluctant to adopt it. Yet by considering features and functionalities, we can consider blockchain technology to be progressive and there is a wide scope of dynamism and innovation in many unexplored areas. Various other challenges in especially blockchain-based healthcare systems are [16]–[25]:

1) The present blockchain-based smart healthcare system lacks in providing a suitable environment for (i) data collection formats and procedures, (ii) a high-quality of service-based data-sharing approach, and (iii) systems interoperability to take full advantage of blockchain technology's features.

2) A pre or emergency data collection procedure in association with government-approved citizens database is required to have data for all patients in any conditions, especially in cases when someone is not able or fit to provide it [26], [27]. Once blockchain-based healthcare approaches are adapted then this data can be collected with the help of biometrics. This would be helpful in multiple sub-systems like patient database, insurance, healthcare monitoring, smart contract designs, clinic trails, surgical operations, etc.

3) Lack of wills and procedures to adopt blockchain technology in the smart healthcare system. It has been observed that there is a wide range of malpractices followed to take financial or other advantages in the present healthcare system. Many stakeholders in the present healthcare system are not interested to adopt blockchain technology because of their losses. Blockchain technology, if adopted properly in a full-fledged system, would be very useful to patients in maintaining their health within a reasonable budget. On the other hand, it would be very good for any country to adopt transparent, secure and ethical processes in any system.

4) Lack of active participation by government officials, the federal government, private institutions, etc. in driving healthy policies, practices, laws, and procedures for designing, developing, monitoring and analyzing blockchain-based healthcare systems. A large population is expecting from their government to have fair healthcare practices from their personal experiences. However, such initiatives are lacking from the right authorities.

5) It is a perception that if blockchain technology will be used with industry 4.0 trends then it would be very difficult to handle data as all citizens (including patients) information would be available publically in any failure. The truth is that if a system is designed and tested properly before implementation then the chances of such leakages are minimal else data leakage can occur in any scenario and malicious entities would always be available to take advantage of it.

6) Presently, the replacement of doctors with robotic surgeries is not feasible over a large scale. Thus, there are no chances of full automated surgical systems. Human (doctor and medical staff) interventions are mandatory in the current time. In conclusion, the smart healthcare system would give more advantages to all stakeholders rather than having a perception of any replacements.

In nutshell, the present healthcare system is complex, cumbersome and costly. Thus, healthcare 4.0 and blockchain 3.0 trends are considered and objectives designed for this work are as follows:

1) To explore the state-of-three-art work and identify various challenges, problems, solutions, security issues and research directions in the healthcare system. Further, a comparative analysis of state-of-the-artwork is necessary to prepare and identify the similarities and differences in existing approaches used so far that helps in the identification of research gaps and propose a solution.

2) To propose blockchain technology and Healthcare 4.0 trends based smart healthcare system. Here, the use of healthcare 4.0 trends including IoT, IIoT, cloud computing, cognitive computing, and artificial intelligence (AI) concepts are explored in detail to propose a smart healthcare system that meets the requirements of the future.

3) A smart contract is an integral part of blockchain technology. One of the objectives of this work is to design and test the smart contracts for the proposed smart healthcare system. A smart contract is planned to be designed and developed in solidity language and supported to the Ethereum network with Metamask wallet.

4) To integrated the simulation-optimization process with the proposed approach and improve the performance of industry 4.0 networks and overall system. The simulation-optimization based objective functions are required to statically prove the working of the proposed approach with efficient direct and indirect variables.

5) To simulate and implement the proposed approach through multiple simulations and implementation approaches. The objective of the use of multiple simulators in this work is to test the functionality of every system and its sub-systems. Now, simulators are designed and developed considering specific needs. Thus, multiple simulators are required to be identified and used for the proposed approach. This way, all systems and sub-systems functionalities can be verified and validated. In an implementation, the blockchain network is planned to be developed with the help of the Ethereum network and solidity based smart contract considering various blockchain tools (Ethereum virtual machine, Metamask, Remix, Ganache, Athena web interface, etc.) and test the functionalities.

The rest of the study is organized as follows: a comparative analysis of blockchain-based healthcare state-of-the-art approaches is presented in section II. Section III presents the problem statement considered to solve the challenges of the present healthcare system. Section IV proposes smart healthcare system designs consider for problem solution, experimentation, and analysis. Section V presents the smart contract designs considered for evaluations and integration with the proposed smart healthcare system. Section VI shows the simulation-optimization processes followed in the smart healthcare system, IoT and IIoT networks. IoT and IIoT networks are the backbone of the proposed smart healthcare system. Thus, process optimization possibilities and integrations are explored in this section for improving the quality of the overall system. Section VII presents the simulation of the proposed system with JaamSim and JSImgraph simulations. JaamSim simulator test and validated the integrity of sub-systems and overall system. Whereas JSImgraph simulation with the queuing theory is used to test and validate the internals of sub-systems and overall system. This section also presents the results and analysis. Section VIII presents the implementation and results analysis of the proposed smart healthcare system with the Ethereum blockchain network. Finally, section IX concludes the work and presents future directions as well.

II. LITERATURE SURVEY

Ahmad *et al.* [28] conducted a survey of blockchain technology and its significances in the present healthcare environment. It is observed that there are many advantages of blockchain technology in medical databases. It brings immutability and transparency with advanced digital frameworks. The blockchain network is found to be secure with novel challenges generated every second and put forward in the form of hashes. There are a large number of the organization who take care of patient's data and patient are interested in hand-over this data to them because they found it difficult to manage their historical data records and fetch it at any place as and when it is required. Blockchain has made the life of every stakeholder much easier by storing their data securing and make them available quickly as and when it is required. This work has identified that there are many blockchain frameworks proposed in the literature that has explored the subject, difficulties and future scope in detail. However, there is a need for work to be done to verify the frameworks and testing in real environments.

Gross and Miller, Jr. [29] identified that blockchain technology has a learning healthcare system functionality inbuilt. This functionality allows patients to share their data secure and built trust in a system that is highly required because it solves various issues like data security, data privacy, optimizing patient's obligations in change or manipulations in data etc. Optimization learning processes train the system from medical data and make it convenient to share in a secure environment considering legal aspects. This work has majorly concentrated over data security and privacy, engagements, accountability and building patient trust in the system. Now, the patient is found to have great trust in the system and he knows that the system has security and self-learning capabilities that would give benefit to him only. This study has found that there are many shortfalls in the present version of blockchain-based healthcare system like the patient is unaware that how blockchain-based healthcare is different from digital records based healthcare system, how data of one treatment at one place would be made available at some other place, does the system have capabilities to integrate to self-learn the non-medico requirements (like insurance, transportation, facility rooms, etc.). Tripathi *et al.* [30] explored the technological, social and security barriers in adopting a digital technology-based smart healthcare system. The author has given preference to the user's experience in following the instructions of the digital healthcare system. These instructions are analyzed with the view of the user's perceptions and tried to solve by proposing a blockchain technology-based secure and smart healthcare system. Here, data security is given a major concentration by discussing the intrinsic security and integrity features of the proposed framework. Various other challenges in adopting the blockchain in the healthcare system include (i) mechanism required to collect, share, exchange or store medical data, (ii) designing a smart contract would be difficult when patient data is not available due to numerous reasons, (iii) how data will be adopted from existing medical or health records to the blockchain network, (iv) lack of patient's knowledge regarding the advantages of blockchain use in healthcare, (v) lack in government initiatives to promote blockchain-based solutions in application development and their uses, and (vi) healthcare industry is dependent over understanding the patient conditions and emotions whereas blockchain-based solution will enhance automation through the data-centric process. Further, this work has designed a framework with a study of types of sensors that can be integrated with the human body through various means and act as a source of data for blockchain-based healthcare solutions. An initiative to design a framework is appreciable however, steps are necessary now to start adopting similar frameworks in real-experimentation and test the applicability of each of the sub-system and their integrations. Hussien *et al.* [31] conducted a detailed, comprehensive and substantial analysis of research articles in blockchain technology searched from three databases IEEE, Web of Science and ScienceDirect using keywords like 'blockchain', 'healthcare' and electronic 'health records'. Relative variations of these keywords are also taken into search results. In this survey, various medical terms necessary to understand the functionality of the blockchain-based healthcare system are identified, defined and analyzed. This study has concentrated to find out the latest designs, frameworks, processes, solutions, models, patterns, platforms, approaches, protocols, algorithms, contracts, white papers, websites, companies, countries, users in countries, etc. and conducted surveys with different statistics. Overall, this article has very articulately surveyed a detailed blockchain technology-based possibilities in healthcare systems and trends adopted in the positive progress of all of the healthcare-based systems and sub-systems. The base of doing such a comprehensive survey if formalized by narrating research questions and self-identification of possible solutions. Next, a flow process is presented that shows the selection of research articles, execute screening through group discussions, deciding the eligibility to consider it for writing a survey in discussions and finally including with pre-defined details. In the analysis, authors have identified that the IEEE publication resource is widely accepting articles in blockchain technology related to healthcare solutions as compared to Web of Science or Science Direct. In other analysis, a comparative study of authors in the various countries are identified and conducted, various medical terms in research are performed, components of blockchain technology-based solutions are found etc. Types of problems, their solutions in data security and healthcare, and future directions are studied systematically. Overall, this is a good study of existing state-of-the-artwork in blockchain technology use in healthcare systems. However, the study of how to apply and develop applications with feasible test cases would enhance the survey for those readers who are interested in developing similar approaches. Al-Karaki *et al.* [32] presented decentralized, accessible, scalable and secure access named (DASS)-CARE to healthcare system and services. The proposed framework greatly facilitates the stakeholders in real-time access to updated data. The objective of this work is to improve quality in the healthcare system with the reduced cost of data delivery. In this work, various aspects taken into consideration include standardization of medical records, consensus approach, micropayment systems, and systems integrity and operability. Authors claim that the proposed framework can secure record and exchange medical records, derived in a way that encourage the timely exchange of required information, patient's self-controlled records, and allows data analytics. It is also claimed that the proposed framework supports various healthcare case studies. There are many frameworks proposed to have a blockchain-based healthcare system but it is observed that verification, validation, and testing of proposed frameworks are rarely applied. To analyze the exact working of the proposed framework, similar experiments are necessary to be executed.

Nagori *et al.* [33] identified the challenges in biomedical research and clinical practices in the healthcare system. It has been observed that very few companies have considered digitization of medical data for improving the healthcare practices and most of the data is scattered and has fewer interoperability possibilities. After considering the current challenges in developing countries (like India), the author has proposed a multichain approach for secure and decentralized medical data storage. In this work, data transparency is taken into consideration while claiming that the need for user's data available to them is more important. It is strongly emphasized that the development of a multichain based dashboard system is necessary to timely intimates the users and medical authorities with their records. This work has proposed a workflow for data security, data analysis, and machine learning processes. It is observed that this framework working is neither validated through mathematical model nor it is verified and tested with simulation or implementation. Thus, it would be very difficult to say the working of the proposed framework in a real scenario. Xu *et al.* [34] presented a Haschain approach for data preservation in large datasets. The proposed approach has considered maximum security and cryptography aspects for providing a secure environment. A consensus algorithm with nonce value is also proposed. The consensus algorithm considers the stakeholders/nodes' willingness to insert a new block in the blockchain if it meets the requirements. Further, IoT network data security is considered in with digital signature, hashing, encryption/decryption, and certification processes. This maximum cryptography primitives and protocols are taken into consideration while driving the proposed approach. In addition to cryptography, key management and disease diagnosis data security are explicitly taken into consideration for quality improvement and analysis. In performance measurements, the capacity of blocks, processing time of transactions, and computational and communicational costs are evaluated and compared with the traditional approach. It has been observed that the proposed approach is much better as compared to traditional. Viriyasitavat *et al.* [35] presented state-of-the-art over emerging research directions, challenges, problem statements, applications, etc. in integration with blockchain technology aspects for developing unique solutions. Towards industry 4.0 trends, integration of blockchain technology with IoT, cyber-physical systems and other industry 4.0 trends are considered for digital economy-based applications that can create a potential impact in the nearby future. This work has identified that the number of publications is increasing exponentially taking various Industry 4.0 aspects with resilience, scalability, security, and autonomy into consideration in the business workflow. This work has uniquely identified the technologies for blockchain and business processes with industry 4.0 trends [36], [37]. A layered architecture is proposed as well that considers the value-driven business processes management and execute collaborative business processes. Research challenges in blockchain and industry 4.0 are uniquely identified related to smart contracts, specification languages, integration and interoperability of systems and sub-systems, and security and data privacy concerns.

Table 1 shows a comparative analysis of state-of-the-art blockchain-based healthcare systems and their features. Table 2 shows the comparative analysis of smart healthcare state-of-the-art contributions with overall system features. Table 3 shows the comparative state-of-the-art analysis of security issues discussion in blockchain-based healthcare systems. This comparative analysis either based on keywords selected in the parameter column or detailed analysis and background processes are studies to identify and classify the security events. Table 4 shows the analysis of blockchain technology-based security companies in the healthcare domains worldwide and their roles. Challenges identified in blockchain-based smart healthcare literature surveys are: (i) lack of proper knowledge in healthcare system users to effetively and securly storage of data, and access as and when required, (ii) lack of standard data collection templates, sharing platforms, peer-to-peer connectivity systems, trust in existing healthcare system etc. (iii) proper dynamic framework that ensures secure data migrations from present healthcare system to smart healthcare system, (iv) many developing countries lacks in intentions to provide corruption free or unethical economic benefit based health services, (v) management of EHR, EMR or PHR, (vi) custodian based secure data accessibility, (vii) connectivity among medical technologists to help in developing full-proof system, (viii) many countries do not have standarization policies for cryptocurrencies, (ix) secure management of data in densly populated regions or countries, (x) users are not interested to invest in companies which can handle their historical or ancestral records on payment basis even by knowing that they themselve are not able manage their records which are very much necessary in any treatment, (xi) lack in technological solutions like (usage of industry 4.0 or simulation-optimization) in healthcare for making it advanced and secure [38], [40], (xii) a large number of data leakage and unethical advantages are observed in present healthcare system, and (xiii) unmanaged present healthcare system with failures, thefts, eavesdropping, spoofing, impersonation or other cybercrimes.

III. PROBLEM STATEMENT

This section mathematically derives the context of system requirements. Let U be a set of patients with detailed features including name, age, gender, diagnostic medical treatment etc. Let W is the set of transactions between patient and hospital during a fixed duration t using wallet V. Thus, a transaction set W_{u_i} for patient $u_i \in U$ contains a set of all i^{th} user transactions $\{w_{u_1}, w_{u_2}, w_{u_3} \ldots w_{u_n}\}$ during time t. Now, each and individual transaction is a tuple $w_{u_i} = \{V_{u_i}, h_j\}$ of wallet and hospital i.e. i^{th} user performs a transaction with j^{th} hospital with wallet V_{u_i}. Thus, w_{u_i} defines the relationship between patient and hospital. Now, the hospital provides services to the patient with taking its transaction w_{u_i} into consideration. All of these transactions should be immutable, transparent, secure and exchanged faster over the reliable channel. Additionally, data should be available as and when required for analysis and predictions.

All of these features are possible with industry 4.0 trends in healthcare only. In conclusion, transaction tuples w_{u_i} can be used to identify data with industry 4.0 trends and with blockchain verifiability and validity. In simulation-optimization, a set of blockchain's blocks $\{b_0, b_1, b_2, b_3 \ldots b_n\}$ as act inputs for every sort of data. The optimization needs to be performed over blocks using dependent and independent variables with their objective functions. These objective functions consider block's transactions to measure smart healthcare system performance and IoT based network performances. Further, these performances need to be optimized by finding local-global input solutions to the objective function.

IV. PROPOSED BLOCKCHAIN DESIGNS FOR SMART HEALTHCARE SYSTEMS

Fig. 1 shows one proposed blockchain technology-based smart healthcare system design taken for analysis. In this system, patient, doctor, staff, hospital, blockchain data system, drug supplier, drug distributor, equipment supplier, equipment distributor, medical board, actuators, medical pharmacies, and government authorities are taken as stakeholders. The proposed system has the following major features:

A. UNIQUE IDENTIFICATION SYSTEM

Every entity in the system is assigned a unique identification. To every physical medical equipment or medicine pack, an RFID tag is attached for unique, secure and faster identification. Similarly, an RFID based identification card is given

TABLE 1. **Comparative state-of-the-art blockchain-based healthcare systems with blockchain technology features.**

Author	Year	Goals	1	2	3	4	5	6	7	8	9	Strengths	Weaknesses
Yue et al. [41]	2016	To propose an App architecture for patients to share data securely, and with proper control and monitor using the blockchain-based intelligent healthcare system.	X	✓	✓	X	X	✓	✓	X	B	A healthcare data gateway application is developed. Working is not properly tested or validated.	The designed application is not decentralized. Security and smart-contract issues are briefly touched.
Zheng et al. [2]	2017	To cover a comprehensive overview of Blockchain technology	X	X	X	X	✓	✓	X	X	S	Discussed briefly over every aspect of blockchain technology Considered health information as a major application	A much depth or detailed comprehensive overview is missing.
McGhin et al. [42]	2019	To conduct a comprehensive survey of blockchain technology use in healthcare systems. To identify research challenges and opportunities in this area and validate them through quantitative and qualitative surveys.	X	X	X	✓	✓	✓	✓	✓	S	A high quality quantitative and qualitative survey is conducted to explore the application, challenges, issues, research directions, possible solutions etc. in blockchain-based healthcare systems.	A comprehensive survey of blockchain-healthcare integration is proposed. However, a comparative analysis of healthcare system challenges with other systems can give the advantage to accept this concept with more weightage.
Witchey, and Holdings [43]	2019	This work has presented healthcare transaction validation systems and methods in a chain of transaction blocks. A patient's lifespan is considered to include his/her any form of inputs and outputs, clinical trials, results etc. information in the blockchain network.	X	✓	X	✓	✓	✓	✓	X	I	A detailed process of record validation in the healthcare system is presented with systemic blockchain creation and integration. A unique process of peer validation is proposed to ensure data security in all of its stages (storage, processing, and transmission).	Industry 4 trends can be integrated to take advantage of globalization with enhanced security primitives and protocols. Processes like cloud computing, cognitive computing, mobile computing, artificial intelligence etc. would meet the future requirements.
Viriyasitavat et al. [35]	2019	In this work, state-of-the-art research is conducted to evaluate the blockchain technology challenges and applications in the design and development of various business processes management models like healthcare, banking, and payment, insurance, digital supply chain, energy management, voting, recruitment etc.	X	X	X	✓	✓	✓	✓	✓	S	A well-structured survey of blockchain technology advantages in multiple business management models and feasibility studies are conducted. Research challenges (including security aspects) and future directions are very well formalized.	Quantitative surveys would add more advantages to conducted qualitative reports.
Ben Basat and Ronca [44]	2019	To measure quantitatively and qualitatively the effects of blockchain technology and its application in Sweden's digital healthcare system.	X	X	✓	✓	✓	✓	✓	X	S	Advantages of blockchain in healthcare globalization, data privacy, data security, data ownership, and system protection are taken in the study to accept this technology widely in the healthcare industry.	Adoption of technology and its advantage with small to medium scale implementation would be more advantageous and meaningful to the healthcare industry.
Ahmadet al. [28]	2019	To explore the blockchain technology features and their advantages in proposing application scenarios in the healthcare system.	X	X	X	X	X	✓	✓	X	S	A brief survey of blockchain in healthcare is studied with an expectation to accept that technology in universal's healthcare systems in nearby times.	A large number of articles have discussed blockchain advantages in healthcare but a few articles quantitatively and qualitatively explored this field of research.

TABLE 1. ***(Continued.)*** **Comparative state-of-the-art blockchain-based healthcare systems with blockchain technology features.**

Gross et al. [29]	2019	To discuss the ethical implementation of blockchain technology in the healthcare system. The importance of adopting blockchain-based processes and their advantages in the healthcare system are discussed.	X	X	X	✓	✓	✓	X	X	S	Blockchain technology advantages like transparency, immutability, security are discussed with ethical implementation into consideration.	Experimental evaluation, mathematical proposals are missing.
Tripathi et al. [30]	2019	This work has surveyed the technological and social barriers in adapting the smart healthcare system after studying, reviewing, exploring ad adopting subject-expert views and general perceptions.	X	X	X	✓	✓	✓	✓	✓	S	Blockchain technology adoption in context to the Indian healthcare system is explored in detail. A detailed framework of the secure and smart healthcare system is designed and developed.	The proposed framework validation and verification is necessary. The integration of various sub-systems should be tested before adoption.
Hussien et al. [31]	2019	This work has proposed a comprehensive survey over developing a Blockchain technology-based healthcare application, and systems are studied.	X	X	X	X	X	✓	X	X	S	There are three categories of blockchain technology in healthcare are explored: (i) designing and developing blockchain-based healthcare application, (ii) evaluation and adoption of blockchain in their existing systems, and (iii) integration of blockchain in healthcare applications.	A comprehensive survey of existing blockchain-based applications in healthcare-related fields could be added to this survey. Blockchain technology aspects can be surveyed in depth.
Al-Karaki et al. [32]	2019	A Decentralized, Accessible, Scalable and Secure named (DASS)-CARE healthcare framework is proposed that uses blockchain technology for medical records, improving the healthcare quality, lowering the costs involved, medical record management, and patient ease in records statistics.	X	X	X	✓	✓	X	✓	X	S	Author claims in security, integrity, and confidentiality of medical records using blockchain and cryptography aspects. Challenges of sub-systems interoperability and cost of its implementation are taken into consideration for comparative study against traditional practices.	The framework is not tested or validated. No mathematical aspects of security or design issues are taken into consideration. The design aspects are covered from a high-level overview rather than designing in-depth and evaluating its functionality in implementation or simulation.
Xu et al. [34]	2019	This work has proposed a Healthchain approach for large scale healthcare data protection. Patient-doctor treatment data is preserved to avoid medical disputes.	X	✓	✓	X	✓	✓	X	X	B	Fine-grained access control scheme is proposed for healthchain data. Security issues like cryptography primitives and protocols and key management are taken into consideration.	An integrated healthcare system with blockchain and data analytics is not identified for medical specialization treatment.
Tanwar et al. [45]	2020	To design, develop, explore and analyze the healthcare 4.0 application based smart healthcare system and overcome the limitations of traditional healthcare systems To integrated chain code concept using Hyperledger-caliper for electronically stored healthcare datasets and measure network using various parameters.	✓	X	✓	X	X	✓	✓	✓	B	This work considered the healthcare 4.0 trends in designing and simulation healthcare system. The working of various healthcare system stakeholders, like clinical staff, nurse, patient, administration are defined and simulated with well-designed algorithms. The performance of proposed simulated scenarios is measured with multiple parameters.	The design and Integration of smart contracts in the proposed approach are not defined formally. The scalability of the system is tested through increasing the block size, and time rather than increase the number of participants or large-scale hospital inputs. A mathematical model could be derived for the proposed approach to validating tee system functionality as compared to simulation or implementation.

TABLE 1. ***(Continued.)*** **Comparative state-of-the-art blockchain-based healthcare systems with blockchain technology features.**

Nagori et al. [33]	2020	To propose a design having multichain connectivity fr security, decentralization, transparent view, data integrity in medical facilities for storing health record electronically	X	X	X	✓	✓	✓	✓	X	S	Off-chain and multi-chain data traceability, transparency, incentivized data access, and authorized drug supply traceability features for the healthcare blockchain network	The proposed approach lacks invalidation through implementation or simulation.
Proposed approach	2020	To design, simulate, implement and analyze the performance of an Industry 4.0 and Blockchain-based smart healthcare system with security primitives and protocols are taken into consideration.	✓	✓	✓	✓	✓	✓	✓	✓	B	Industry 4.0 trends based smart healthcare system with novel smart contract design, validated through simulation and tested with implementation.	–

1: Simulation, 2: Implementation, 3: Performance Measurement, 4: Smart-contract design, 5: consensus algorithm, 6: Cryptography Issues, 7: Decentralized Application (Dapp) development, 8: Industry 4.0 trends, 9: survey (S)/implementation(I)/Both(B)

TABLE 2. **Comparative analysis of smart healthcare state-of-the-art contributions with overall system features.**

Author	Year	1	2	3	4	5	6	7	8	9	10	Comments
Esposito et. al. [46]	2018	X	✓	✓	✓	X	X	X	✓	X	✓	This work has proposed an ecosystem for electronic health records, medical health records, and personnel health records. However, verification and validation of the proposed ecosystem are necessary to have a better understanding of its implementation in real-environment.
Tripathi et al. [30]	2019	X	✓	X	✓	X	X	✓	✓	X	✓	Validation of the proposed framework through mathematical, simulation or implementation would increase the work significance.
Gross et al. [29]	2019	X	✓	X	X	X	X	X	✓	X	✓	Ethical discussions over blockchain technology's advantages in the healthcare system are discussed in detail. However, the advantages of real-scenario integration should be given more advantages.
Xu et al. [34]	2019	✓	X	✓	X	✓	✓	✓	✓	X	✓	This work proposed a Hashchain i.e. a mechanism to preserve data in a large scale health dataset. The proposed approach is integrated with IoT but it lacks incomplete industry 4.0 integration. The proposed approach is mathematically sound to validate the framework and it can be enhanced with industry 4.0 trends to increase the scalability and bid health data creation.
Viriyasitavat et al. [35]	2019	✓	X	✓	X	X	X	✓	✓	X	✓	These works have unique framework designs, applicabilities areas of blockchain technology, future challenges, and research directions. This is a brief but comprehensive survey. The author should increase the quality and quantity of this survey by identifying a large number of articles published in different areas that use blockchain technology.
Tripathi et al. [30]	2019	X	✓	✓	✓	X	X	✓	X	✓	✓	This work has presented a detailed survey with all industry 4.0 trends that can be integrated with the healthcare system to make it a smart healthcare system. However, validation of the proposed approach using statistical or implementation tools is necessary to cross-check its functionalities in real-environment.
Tanwar et al. [45]	2020	X	✓	✓	✓	✓	✓	✓	✓	X	✓	Smart contracts and mining processes integration would exactly reflect the performance of the overall healthcare 4.0 based clinical trial system. Thus, if these concepts are integrated then it should have been explicitly mentioned with detailed design.
Farouk et al. [47]	2020	✓	X	X	✓	X	X	X	✓	X	✓	This work has surveyed the Blockchain platform for healthcare and concentrates on various aspects of Blockchain technology and its applicability in healthcare systems. This work discusses data security aspects (including organisation providing this service across the globe) only. There are many cryptography and security aspects in different stages of data that need to be addressed.
Mackey et al. [48]	2020	X	✓	X	✓	X	X	X	X	X	✓	This work has concentrated over the survey of blockchain-based healthcare services and applications as compared to the present healthcare system. It would be more feasible to switch from the present system to a blockchain based solution if use cases should be prepared and the system is developed from small scale implementation to a large scale.
Proposed Approach	2020	X	✓	✓	✓	✓	✓	✓	X	✓	✓	In the proposed work, various aspects (including architectural, model, framework and security) are taken into consideration while proposed blockchain-based smart healthcare system.

1: Detailed Survey, 2: Brief Survey, 3: Architecture proposal, 4: Framework design, 5: Algorithm writing, 6: Protocol formalization, 7: Novel system/scheme design, 8: Partial Industry 4.0 trends, 9: Complete Industry 4.0 trends, 10: Security issues

to every person (including doctor, staff or any third person). There is no exception given to anyone to have a temporary identification tag including patients as well. This is because everyone has a unique national (national ID cards, driving card number, etc.) or international identification numbers (passport number). These entities are stored in the database with the help of blockchain technology. Now, even if a patient is interested to get operated in different or multiple hospitals

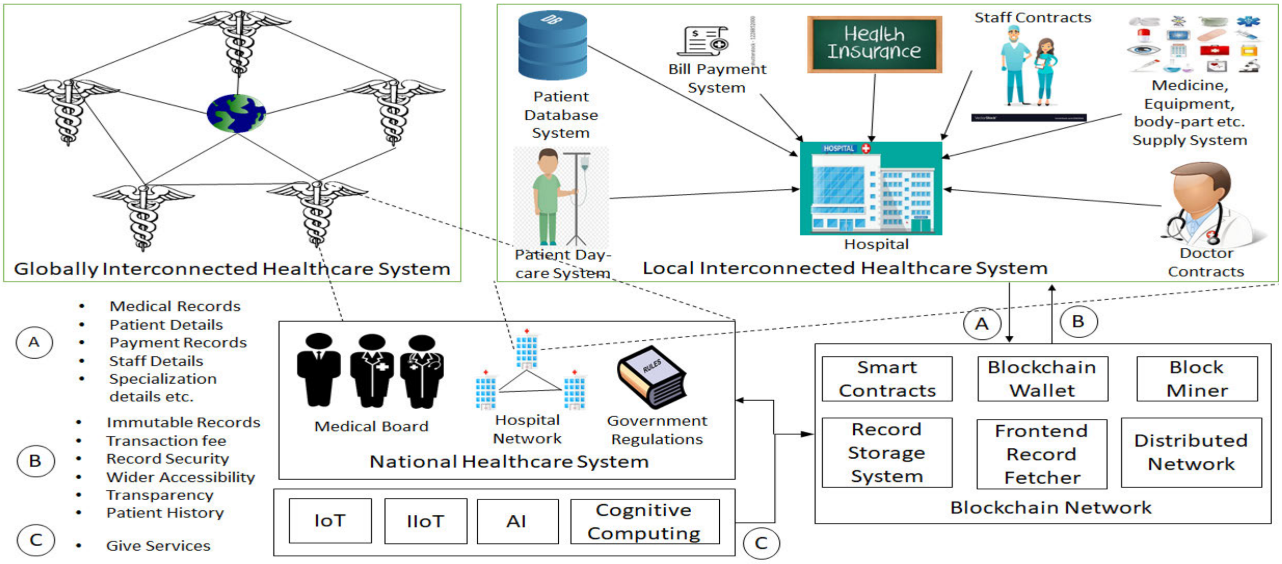

FIGURE 1. Proposed blockchain and Industry 4.0-based smart healthcare system.

TABLE 3. Comparative state-of-the-art analysis of security issues discussion in blockchain-based healthcare systems.

Parameter	References
Confidentiality	[8],[12]-[14],[29],[33],[34],[42],[45]
Integrity	[8],[12]-[13],[16],[29],[33],[34],[42],[45],[46],[48]
Authentication	[17]-[20],[29],[31],[33],[34],[42],[45],[46],[48]
Non-repudiation	[16],[34],[42],[45]
Resource availability	[28],[31],[32],[42],[45]
Users availability	[21],[28],[31],[32],[42],[45]
Network availability	[21],[28],[31],[32],[34],[42],[45],[46]
Data storage security	[3]-[7],[28]-[34],[42],[46]
Data communication security	[3]-[7],[28],[30]-[34],[42],[45],[46]
Data processing security	[3]-[7],[28],[30],[33],[34],[42],[45],[46]

at the same or different timings then all records through public blockchain are easy to trace or update as well.

B. BLOCKCHAIN-BASED IMMUTABLE, TRANSPARENT AND SECURE DATA RECORDER

Blockchain technology has various advantages such as, it can store any record in an immutable form. In the proposed system, all information regarding patients, doctors, hospitals, suppliers, distributors, etc are stored permanently with a timely update of change in records, if any. For example, patient's historical medical records are important to learn and it is very difficult to explain or physically keep every record in everyone's custody and produce to doctor at the time of treatment like in present healthcare system scenarios. As every doctor has his/her own clinical trial experiences, and medicines or treatments of each of the doctor may or may not be the same as other doctors. Thus, it is mandatory to keep the historical record of every person to have better and highly successful treatments. It is usually observed that the majority of medical treatment are interdependent. For example, if any patient has to undergo kidney stone treatment, transplantation, dialysis etc. or any type of transplantation then Blood pressure or Sugar levels should be within controlled limits otherwise it may harm other parts of the body. Thus, it is necessary to have an accurate and timely medical record of every person available remotely and timely to the consulted doctor.

All medical and other related records are transparent using the blockchain-based healthcare system. As discussed earlier, patient's records are necessary at every step and every time it consults the doctor or undergoes some treatment. It is even recorded to know by himself that what medicines or treatments are good for his/her health. Transparency through blockchain is a secure way of making such information available to concerned persons as and when required.

Security is a major feature incorporated in blockchain technology to enhance its applicability and adoption in a wider range of applications. Patient's person records (including national or international identification numbers, family connections, account details etc.) will be available over third party systems if one opts to go for implementation and use of blockchain-based applications. Blockchain technology uses cryptography primitives and protocols for its secure designs. Here, there are possibilities to integrate both lightweight and heavyweight cryptography primitives and protocols. Lightweight cryptography primitives are necessary to secure fetch, store or update information from devices where resources are scarce. Almost all of the medical equipment or drugs do not have any sort of computational, storage or communicational capabilities. Identification devices or sensor devices attached to these pieces of medical-equipment have very limited computational, communicational or storage powers. Further, these identification or sensor devices are required in the proposed system or construct an Internet of Things (IoT) or Industrial Internet of Things (IIoT)

TABLE 4. Blockchain technology-based security companies in the healthcare domains and their roles.

Company Name	Country	Role
Central America		
Burstiq	USA	Uses blockchain technology in complex data management, connection medical solutions, immutable health identifications for every entity, granular data ownership, designing application interfaces, compliance to various medical international standards, etc.[49].
Centers for Disease Control and Prevention (CDC)	USA	CDC and IBM collaboration provide a blockchain-based solution with a surveillance system, data security, clinical trails data etc. such that public health organizations can easily, effectively and securely collect patients' data and prescriptions. A real-time monitoring system is available using the proposed approach to monitor diseases and their outbreaks. Supply-chain is looked after to monitor diseases with timestamps, peer-to-peer network-based reporting, data processing, performing medical research and patterns, etc.[50].
Chronicled	USA	Build a chain-of-custody based blockchain network. This organization is active in involving lar enforcement to review suspicious, criminal or harmful drug trafficking cases in pharma companies' supply chain. Additionally, a distributed ledger is designed in such a way that security is the prime importance of any medical supply chain considered in this organization. This activity ensures safe arrival with detailed reports in a drug delivery system [51].
Coral Health Research & Discovery Inc.	Canada	Provides blockchain-based faster care processes, automated administration, health outcome measurements, patient data in a distributed ledger, connect stakeholders, smart-contracts integration, security and data protection etc. This organization is unique in providing the patient's own record management, tracking, and handling process [52].
Curisium	USA	Provides smart-contract based secure, efficient, scalable and data management solutions in pharma products and payment systems [53].
DOC.AI	USA	Provides study over the use of artificial intelligence in allergic reactions, sharing medical and genomic data in medical researchers' community and securing store, process and exchange data in blockchain network using security and privacy life cycle [54].
Encrypgen	USA	Provides user profile with medical and behavioral data. Additionally, it is doing self-analysis to share their own network learning medical experiences with data analytics. In the future, the blockchain-based used approach will be used for partnerships with testing and analytics companies for enhancing the quality of their findings. Blockchain-technology makes it easier to search, store, buying, selling and exchange genetic records. This approach is taken into the study for enhancing the quality of work in the biomedical and healthcare industry [55].
Factom	USA	Provides blockchain-based customized solutions in medical data registry, verifiability, global connectivity, cryptography key management, without cryptocurrency, better infrastructure management, fast connectivity, Blockchain-as-a-service, trusted process flows, etc. [56].
Gem	USA	Provides a cryptocurrency-based free application for patient portfolio building and tracking [57].
Guardtime	USA	Provides services to healthcare companies and governments in integrating blockchain-based security solutions to their cyberspace. It is providing active blockchain-based services to Estonia's healthcare and started working in the United Arab Emirates through a private organization. Cybersecurity applications include healthcare with blockchain technological aspects are a prime area of working [58].
HealthWizz	USA	Provides mobile application in generating, storing and accessing clinical trial based data using blockchain-network security [59].
Medcredits	USA	It provides worldwide connectivity of patients and physicians, centralized storage of data, and avoid costly and time consuming compliance burdens [60].
MediLedger	USA	Provides data sharing in consideration of cross-industry business rules, protects business intelligence, secure connectivity, trading, and trusted services [61].
Nebula Genomics	USA	Provides distributed ledger technology to study and record genetics records with lower costs. A secure, giant and easy-to-access database is created by removing the middleman and incentivizing services [62].
OncoPower	USA	Provides services like connectivity and collaboration, drug lookup, customization of patient's medical education, sharing data with peer partners for research and analytics, etc. [63].
Patientory Inc.	USA	It provides a unique end-to-end encryption solution in securing patient data. This organization has created a blockchain-based decentralized database that enables all stakeholders (patients, doctors, clinical trial teams, hospitals etc.) to fetch all important and necessary information. Insecurity, data storage, processing, and exchange is given prime importance [64].
Pokitdok	USA	Uses blockchain technology as platform-as-a-service, member-specific health insurance record management at large scale, compliance to health standards, etc. [65].
Simplyvital Health	USA	Provides services to patients in best and easy healthcare decision making by pre-processing, refining and exchanging of medical and health data. All records are managed through blockchain-based open-source data management processes and procedures [66].
Tierion	USA	Provides regular audit services of medical data in the blockchain network. In blockchain-network, timestamps and detailed entity credentials are stored in proof of the ownership. This activity is executed through the events happening over supply chain management. A clear possession of historical records is maintained to improve the quality of service. This organization has proposed a "multi-network coin" with the use of Bitcoin cryptocurrency and it is observed that this approach enhances its applicability [67].
TimiHealth	USA	Provide services in DNA genetics data, patient's own data control system, sell or purchase DNA genetics data, secure and safe access, distributed ledger-based data storage, rewards system for selling data, etc. [68].
YouBase	USA	Provide security service in data related to allergy status, medical document, lab documents, clinical visits, InPatient encounter, genetic profile etc. Additionally, custodian access to the host profile is available with proper security checks [69].
Asia		
Alibaba Health Information Technology Ltd.	China	This organization has invested in blockchain-based healthcare solutions with services like secure data collection, its availability, accessibility, secure system network, etc. [70].

TABLE 4. *(Continued.)* **Blockchain technology-based security companies in the healthcare domains and their roles.**

Baidu search engine	China	Baidu search engine also started investment in blockchain-based technological solutions in multiple healthcare domains [71].
CallHealth	India	CallHealth and ThynkBlynk's collaborate to kick start blockchain technology usage in the Indian healthcare system to avoid fake or fraudulent data modification, prepare data in absence of data sources, secure and efficient data storage processes, etc. [72].
Thynkblynk	India	Planned but not yet started to use blockchain in healthcare data [73].
Eastern Europe		
Robomed	Russia	Provides AI and blockchain-based solutions considering patients as a single point of care. The procedure followed by this organization includes the user of applications like chatbots, wearable sensors, and tools, telemedicine information-gathering sessions and exchange necessary information with the patient's medical and clinical trial team. The quality of the healthcare system is maintained by incorporating all stakeholders using smart contracts. The main use of blockchain technology lies in secure medical and healthcare records [74].
European Union		
Embleema	France	Deals with medical research studies, digital user selection, secure data collection, patient's consensus for any data issue, data analysis for researchers, and healthcare data regulations [75].
Blockpharma	France	Provides solutions like drug traceability, counterfeiting, verification of drug delivery at every major or minor delivery point, help patients in the identification of unapproved medicine, and fake medicine identification with supply chain management and its delivery system [76].
Genomes.io	UK	Provides genomics data of their participants to organizations for research, clinical trials, and innovations. This organization offers users to control their data, technology partnership, genome sequencing etc. Patients can use this information for different measurements like traits, wellness, health, pharmacogenomics study, etc. [77].
Hearty	Spain	Provides blockchain-technology support to insure with easy-to-use, secure and effective data sharing [78].
Iryo	Slovenia	Provide public blockchain having zero-knowledge based encrypted health data and access control mechanisms. This ensures secure and useful health data with the patient's medical history classification [79].
Medicalchain	UK	Provides Blockchain-based platform for record management, protection for patient identities, security to health and medical records, single point of healthcare system's stakeholders (doctors, patients, hospitals, staff, laboratories etc.) verifiability [80].
MyClinic	UK	Provides secure patient data storage, sharing and processing in partnership with OpenEHR. It handles secure data authorization or access management during and after treatment [81].
Shivom	Switzerland	Provides secure DNA data for research with blockchain-technology to secure and protect it [82].
Middle East		
Proof Work (Israel)	Israel	Put patient's data over the decentralized platform, easy connectivity, efficient historical data accessibility, autonomous governing, etc. [83].

networks as required in Industry 4.0 trends to have smart technology. The scarcity of resources available over such devices enforces the system to have lightweight cryptography primitives or protocols for high-security standards with lighter performance-based security algorithms. Finally, information stored in public or private blockchains is available at any location and at any time because Blockchain technology is distributed and decentralized in connectivity.

C. PATIENT'S DECISION MAKING

The proposed system is helpful to patients or their family members in medical treatment based decision making. This can be better understood from the patient's state of mind just before going to make his/her mind to have a particular type of medical treatment. As discussed earlier as well, every doctor has a different set of clinical trial experiences and success rates. Now, if a non-medico person is visiting multiple doctors to take medical opinions then there are high chances that every doctor suggests a different medical treatment procedure. It is quite possible because of the advancement of technology has given such viable options. Now, it is necessary to have not just every doctor but every treatment's success rate records with detailed medical procedure explanations. In real-scenarios or emergency conditions, it is observed that patient does not undergo such record checking and go with nearby hospitals and best treatment available with selected hospitals. On the other hand, the doctor does with the treatment in which he/she is experienced or interested without taking much of its success ratio. Now consider a scenario in which a trained system with timely and accurate information providers having blockchain's immutable, transparent and secure environment provides a patient with immediate records of successful treatments, doctors and hospitals while keeping all of his medical histories with him. In such scenarios, it would be much easier for anyone (patient or family members) to make a quick decision. This encourages healthy medical practices in the complete healthcare world.

D. DRUG TRACEABILITY

One can easily experience through one's own learning that there are many counterfeit drugs are available in the market. Many of them are manufactured or distributed through government-approved organizations. However, there are many cases observed where the government refused or unapproved organizations are selling their products through local pharmacies. A majority of cases or such scenarios are observed in developing or under-developed countries. Now, if every drug will have a unique identification number, its history of clinical research trials and government approval

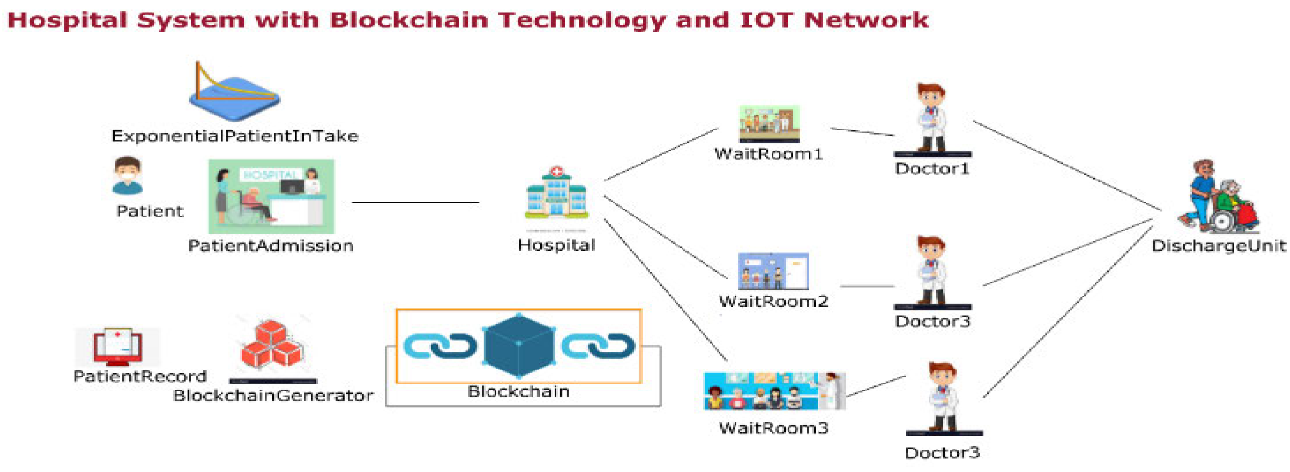

FIGURE 2. A topology demonstrating the blockchain-based healthcare system.

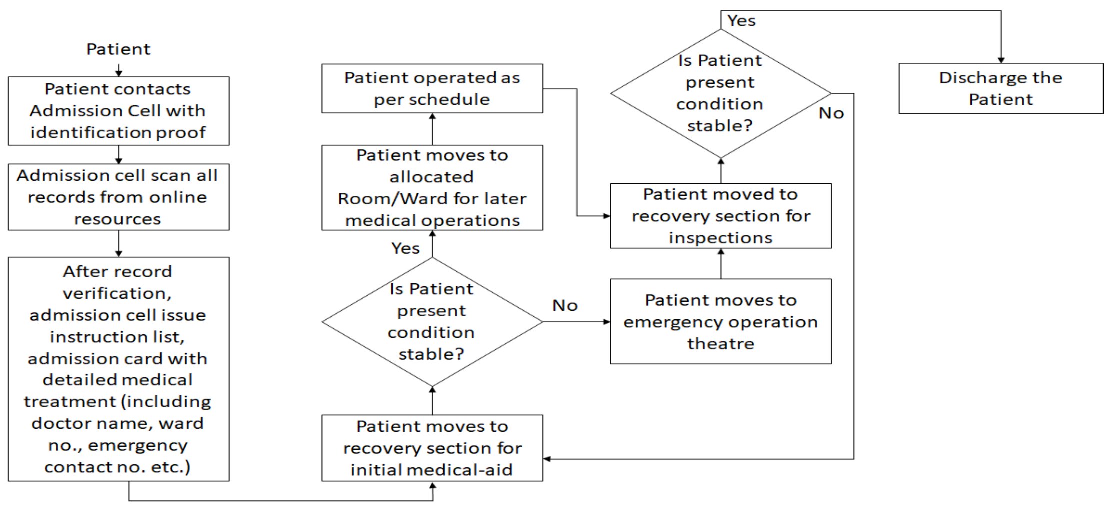

FIGURE 3. Patient process flow cycle in the smart healthcare system.

letters available publicly then it would be much easier for every stakeholder in the healthcare system to have much higher trust in the system. This is one of the major keys behind the success of similar systems.

E. INTERNET OF THINGS CONNECTIVITY IN THE LOCAL REGION

Using Industry 4.0 trends, it would be mandatory for everything in the system to have identification and sensor system. Internet of everything in small to medium scale regions constitutes IoT network to be managed at different levels (department, hospital or even in a city). An IoT connected healthcare system will have all thing's records in the network and it can make available to everyone as and when required. This type of system will auto-generate alerts in case of any discrepancies like drug expiry, equipment failure, doctor-state of mind, patient health condition fluctuations, etc. In conclusion, a hospital or doctor having similar facilities can well manage their environment.

F. INDUSTRIAL INTERNET OF THINGS CONNECTIVITY IN THE GLOBAL REGION

Similar to IoT connectivity in the local region, Industrial Internet of Things (IIoT) connectivity in global region (including interconnectivity of multiple cities, states or even countries) healthcare system would be much easier and beneficial. IIoT interconnects a large number of cross-city and cross-domains healthcare systems. This connectivity will elongate the availability of information to a much wider range. Thus, treatment data and related analytics will be available to patients in a much accurate and fast mode. In considerations of the above-discussed feature of the proposed system, Fig. 2 shows a blockchain-based Healthcare system. The complete patient interaction with the smart healthcare system and process flow is explained through a flowchart as shown in Fig. 3. In this system, the patient takes admission in the hospital with a consultation to the patient admission cell. In patient's registration with patient admission cell, it gives his/her personal information, medical history record

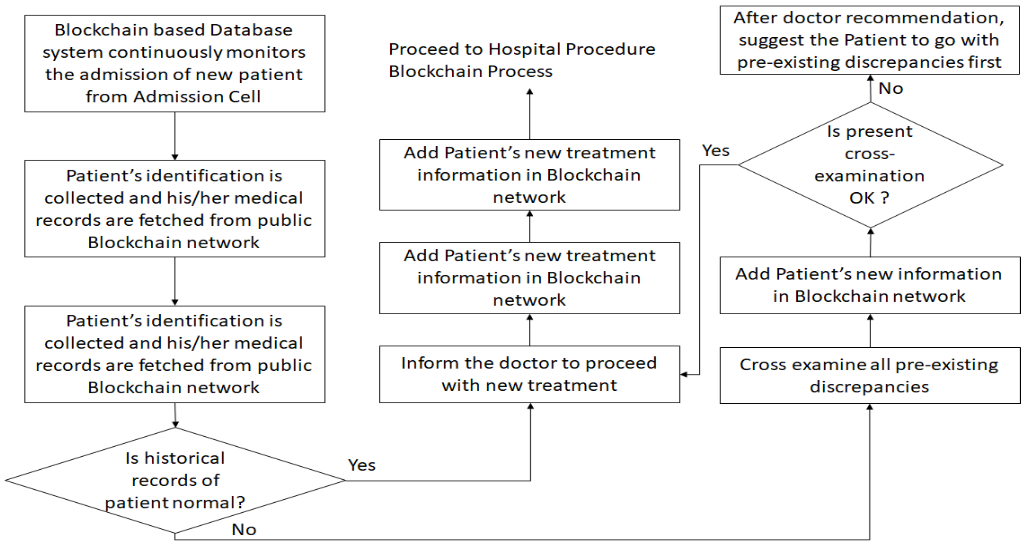

FIGURE 4. **Admission cell and initial consultancy-based blockchain process flow cycle in the smart healthcare system.**

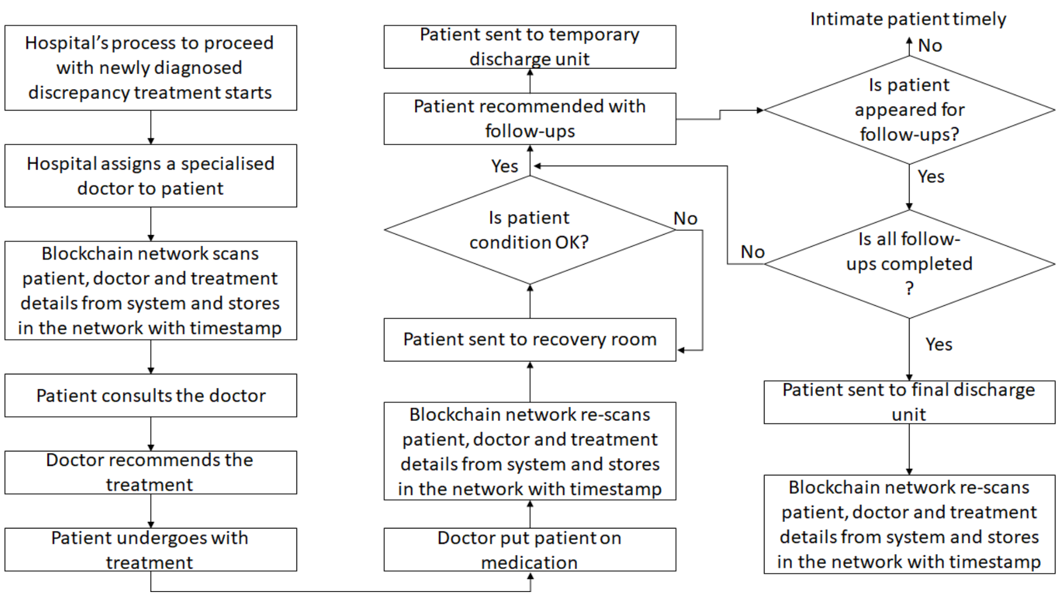

FIGURE 5. **Hospital process flow cycle with blockchain technology in the smart healthcare system.**

(if any), medical insurance (if any) and type of room service (ward/private room). After registration, the blockchain-based database system auto fetches the patient's history (if exists) from the blockchain network. All information is shared with the doctor assigned to the patient as per the hospital legalize process. In parallel, a patient goes through initial medical aid and checkup. If during this initial scanning, any abnormality arises then the patient is put under scrutiny with the support of a doctor else-if patient conditions are normal then it goes through its recently diagnosed ailment. During this whole process of initial medical scan, the blockchain-based database system regularly scans the recently admitted patient progress and timely stores in the database. Fig. 4 shows the detailed admission cell and initial consultancy based blockchain process flow cycle proposed for the Smart Healthcare System. Fig. 5 shows the detailed hospital process after the initial scanning. Hospital search and assign a specialized doctor to patients in records and blockchain technology auto-scans this new information and store in the database. As per the doctor-patient scheduled meeting, the patient consults the doctor and explains the symptoms. After a proper medical examination and understanding of the symptoms, a specialized doctor recommends a treatment. Now, the patient is given time to decide whether he wants to go through the treatment or

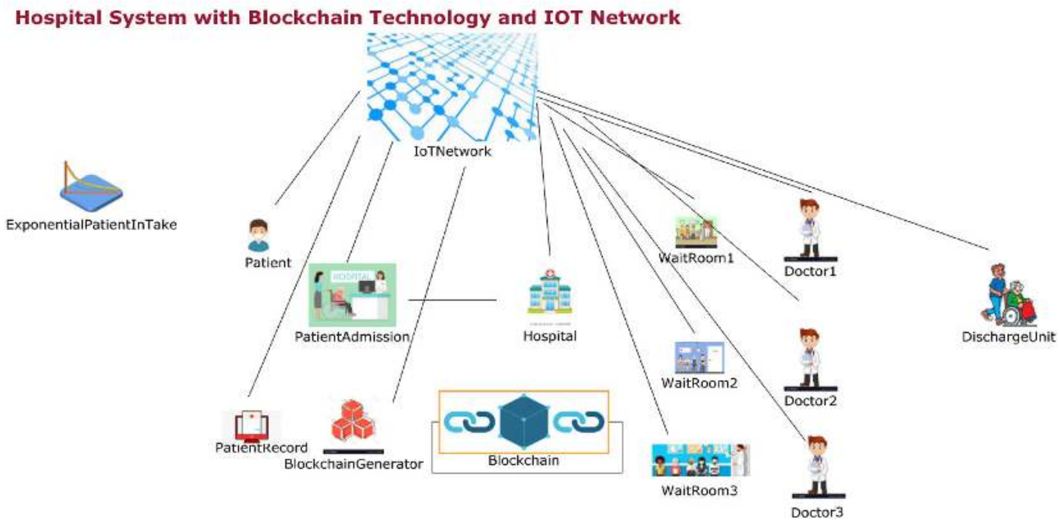

FIGURE 6. Hospital System with blockchain technology and the IoT network where every entity is connected with identification and information.

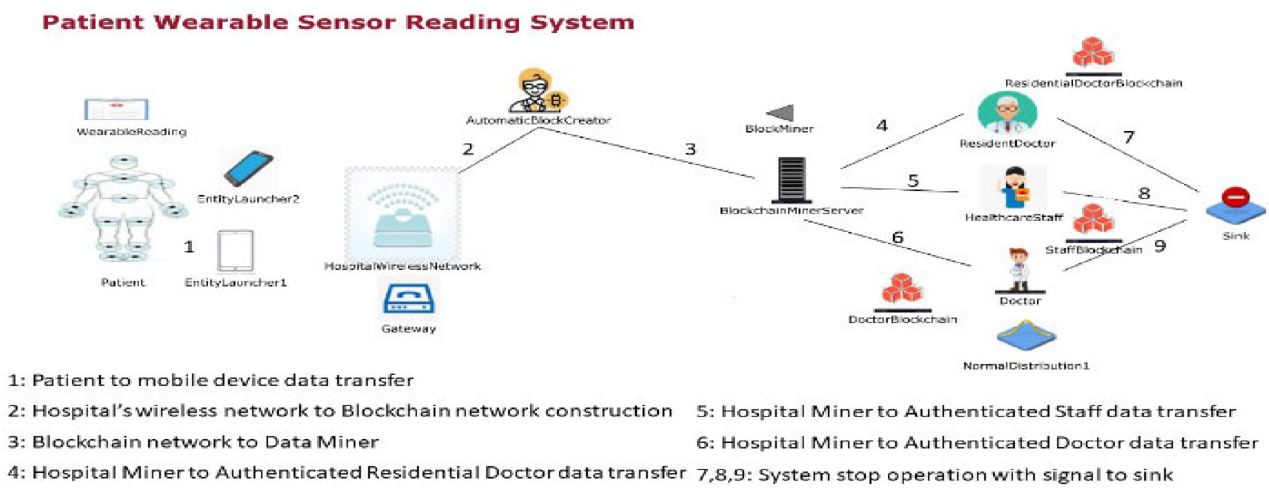

FIGURE 7. An example of patient IoT network for health monitoring using wearable sensor and blockchain technology.

stop any further processing. If the patient decides to undergo treatment then the patient is moved to operation theatre and undergoes the treatment. After treatment, the doctor starts the medication. At this step, the blockchain technology-based database scanner and recorder system are auto-configured to scan and collect the patient's all updated records. Here, all equipment and medicines used are also stored in the blockchain network. The patient is sent to the recovery room immediately after the operation.

In the recovery room, the patient's records are constantly monitored for a fixed duration. Now, if the patient is progressing then it is either moved to the ward/room or sent to the discharge unit as per doctor recommendations. In the majority of cases, the doctor recommends the patient to have regular follow-ups and the hospital monitors these follow-ups. If any patient is missing a follow-up then the hospital takes the responsibility. Fig. 6 shows the hospital system with blockchain technology and the IoT network. In IoT network-enabled healthcare system, every entity is attached with identification and operational piece of information. Starting with patient, doctor and staff member, each of these can be attached with a wearable sensor.

To monitor patient records continuously, Fig. 7 shows a scenario where the patient is attached with the wearable sensor and its information is exchanged through a server to doctor and staff members using processes defined with numbers 1 to 9. In parallel, a blockchain server keeps track of the information, and store and make it available through a wireless network (using process 2 and process 3). Hospital wireless network continuously senses the wireless signals and collect patient records using wireless and/or mobile devices (using process 1). A gateway prepares the records in the

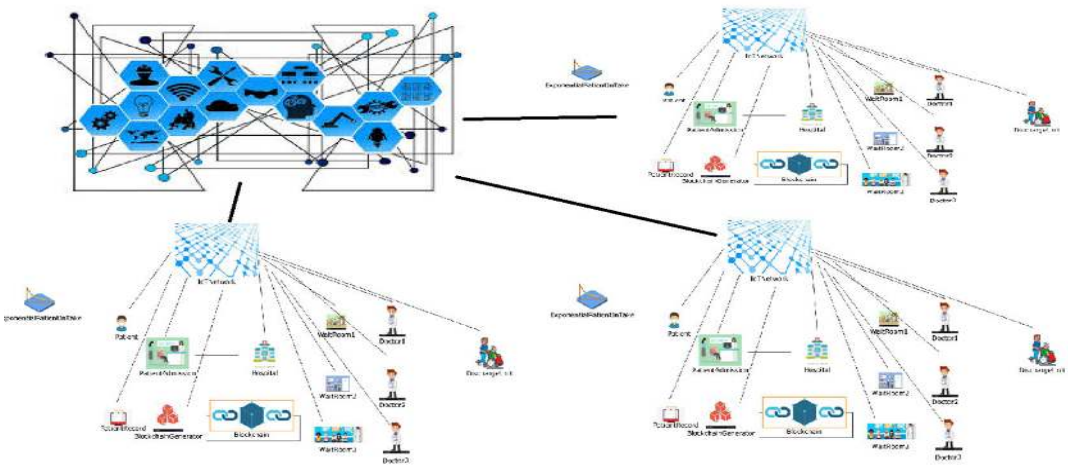

FIGURE 8. Industrial Healthcare Internet of Things (IHIoT) model for the proposed healthcare system.

FIGURE 9. Drug delivery and traceability system system in the IHIoT network designed in JaamSim.

pre-specified format and makes it available to be added to the blockchain (using process 1). Now, the process of blockchain creation starts and information in the form of Block is sent to records in its database. Wearable sensor sense patient medical condition records and BlockMiner. BlockMiner takes care of the transactional fee (in terms of 'gas') and availability of the server. As soon as the server is idle, a block is added to the blockchain network. After adding the required block to the blockchain network, medical information stored in the block is also sent to the residential doctor, healthcare staff member, and specialized doctor (using process 4, process 5, and process 6). Healthcare staff is a constant supervisor of the patient and responsible for patient medication. In case of any record discrepancy, healthcare staff immediately report to the residential doctor. The residential doctor should be available within the hospital 24 × 7 over multiple shifts. The residential doctor can call the specialized doctor in case of emergency or as and when it is required. If any update to patient record is available then the old record is deleted immediately (i.e. sent to sink). Residential doctor, staff member and physician (doctor) activities are constantly monitored (using process 4, process5, and process 6). Their records are added to the respective Blockchain network to monitor their activities. In any treatment, the active members involved are a surgeon (or doctor), department and staff. Algorithm 1 shows the complete activity cycle proposed for a surgeon. Similarly, algorithm 2 and algorithm 3 show the department and staff activity cycles respectively. Algorithm 4 shows the insurance activity cycle.

Fig. 8 shows the Industrial Healthcare Internet of Things (IHIoT) model for the proposed healthcare system. IHIoT is designed to integrate multiple IoT networks in local or global regions. Small IoT healthcare networks are useful and efficient in the local region only. Whereas, large scale integration of IoT networks in the local region or multiple IoT network connectivity at the global region requires IHIOT network. Like blockchain and IoT network-based small-scale healthcare system, IHIoT network also require blockchain technology to maintain their records and blockchain networks. Each IHIoT network can have fog network to improve the

Algorithm 1 Surgeon Activity Cycle

Premises: Let U_i, W_j, V_{u_i} and h_k represents i^{th} user using j^{th} transaction with wallet V at k^{th} hospital. Further, $U_i^{address}$, $W_j^{address}$, $V_{U_i}^{address}$ and $h_k^{address}$ represents the addresses used to store user, transaction, wallet and hospital records. Suppose, U_i^{EMR}, U_i^{EHR} and U_i^{PHR} are the i^{th} user's electronic medical record (EMR), electronic health record (EHR) and personal health record(PHR) respectively. The electronic medical record is all record of a person having all undergone medical treatments, a drug used, allergies, diet plans etc. The electronic health record is considered to be different from the electronic medical record in terms of personal medical practices adopted to maintain health. For example, regular measurements of blood pressure and sugar levels, medical treatment apart from allopathy practices etc. Finally, a personal health record is different from electronic health records and electronic medical records in terms of person's health practices including regular diets, exercise duration, any self-experienced pain or non-functional body part symptoms etc.

Goal: To monitor and control surgeon health and clinical activities.

1. **While** U_i is Surgeon **do:**
2. **If** $U_i^{address}$ is valid **then**:
3. **If** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} are satisfactory **then:**
4. **Fetch** patient's EMR, HER and PHR records
5. **Diagnose** patient
6. **Treat** patient
7. **Update** patient's EMR, HER and PHR records
8. **Else**
9. **Instruct** U_i to go for self or specialized treatment
10. **Update** EMR, HER and PHR records
11. **Else**
12. **Register** $U_i^{address}$
13. **Update** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} records
14. **End While**

Algorithm 2 Department Activity Cycle

Premises: In addition to premises defined in algorithm1, other premises include D_i, $D_i^{specialization}$, $D_i^{address}$, and $T_{D_i}^j$ represents i^{th} department, its specialization, address in the blockchain network (having department records) and j^{th} team formalized for treatment.

Goal: To formalized specialized department team, assign to the patient and prepare patient treatment report.

1. **While** D_i is valid department **do:**
2. **If** $D_i^{address}$ is valid **then:**
3. **If** $D_i^{specialization}$ exist in h_k then:
4. **Formalize** $T_{D_i}^j$ having nurses and technologist
5. **Assign** a specialized surgeon to $T_{D_i}^j$
6. **Treat** patient
7. **Prepare** patient reports
8. **Else**
9. **Recruit** working staff
10. **Register** $D_i^{specialization}$
11. **Else**
12. **Register** $D_i^{address}$
13. **End While**

quality of service and performance. Each of its fog networks can have fog storage, computing, and blockchain networks. Similarly, all of the data collected from IIoT, IoT or fog networks are made available in cloud computing. Thereafter, cognitive computing and artificial intelligence can be applied to improve network statistics and services. Fig. 9 shows the proposed drug delivery and traceability system in the IHIoT network designed in JaamSim. This model considers random and exponential medicines in the production unit irrespective of medicine salt. Thereafter, medicines from multiple drug production, packing, or manufacturing units are delivered to safe medicine storage units. Medicine distributor collects the medicines from different storage units and delivers it to pharmacies (hospital, online or local). Consumers/patients visit the pharmacies with doctor prescriptions and can purchase prescribed medicines. In this complete system, there are chances of counterfeit drugs/medicines which can be a major cause of loss of life. This is one of the major challenges in the present healthcare system in the majority of countries. Lack of knowledge to patients, doctor negligence to earn unethical financial or other advantages, higher medicine cost and profits to manufacturers, higher profits to supplier or distributor, etc. are the major reason for not accepting any change in the present drug supply system. If the present drug delivery and traceability system will be changed to a blockchain technology-based system then each stakeholder (government, manufacturer, clinical trial unit, distributor, pharmacy, and consumer) will have their nodes and corresponding blockchains. In this way, everyone will be bound (through smart contracts) to adhere to the rules, regulations, policies, and procedures defined in the court-of-law ethically and transparently. This type of system will generate immutable records with timestamps for any type of verifications. A historical record based transparent and immutable system will build patient and doctor trust in the network to follow the ethical practices that are good for their clinical trials. Fig. 10 shows a clinical trial-based smart contract system for the blockchain network. Every treatment has a set of pre-experiences clinical trials dataset and this can build trust and transparency to both patients and doctors in the system if such records are available to both of them before going for any treatment.

It has been observed that there are multiple treatments to cure one disease and if a patient visits multiple doctor and every doctor suggest a different treatment then it would be very difficult to decide which one would be right for a patient.

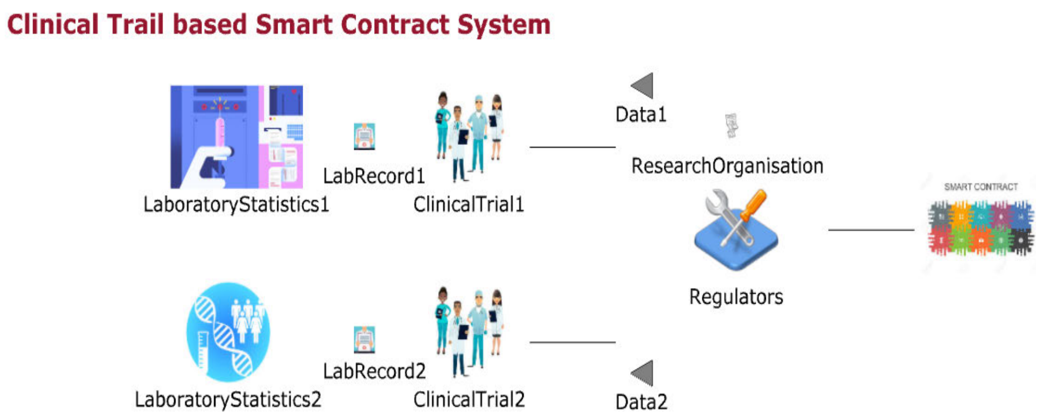

FIGURE 10. Clinical trial-based smart contract system for the blockchain network.

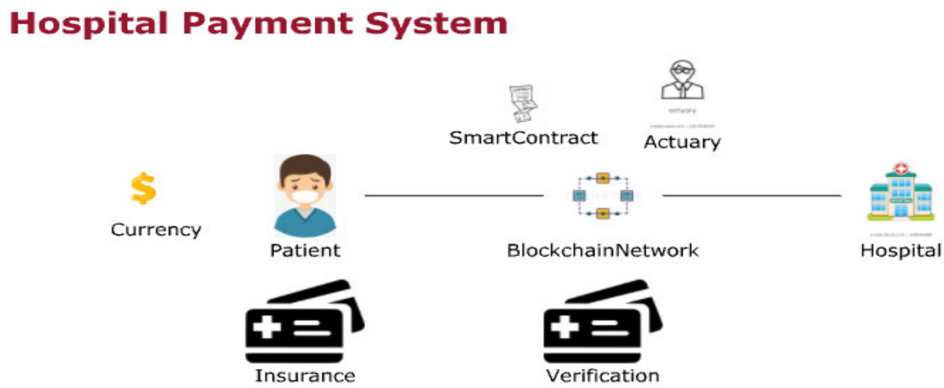

FIGURE 11. Blockchain-based payment monitoring system where patients and hospitals or doctors are bound with smart contracts.

For example, the table 5 shows one such diabetic clinical trial case study. In this case study treatment for a diabetic patient is well-defines and it is dependent on age (young (around 22 or less), middle-age (around 36), old (around 60 or more)). In all such cases, the presenting department, patient history, investigation, and treatment are standard and well done. However, the possibilities of special cases like a patient having less age (around 15 or less) and having severe diabetic issues cannot be ignored. In all such circumstances, the first thing required is to maintain the patient's proper and timely records. This would make a doctor easy to understand and treat the case and build trust for a patient in the system. In such scenarios, it would be easier for the medical board or court to re-examine any such malpractice treatment and resolve the patient-doctor disputes at the right time.

Fig. 10 shows the clinical trail-based smart contract system that is mandatory to be executed before a patient's treatment as described in Fig. 8. In a clinical trial based smart contract system, laboratory medicine experimentations and their detailed reports with success ratios are prepared well-advanced. Thereafter, medicines are tried over a sample of the patient in a controlled environment. After satisfactory clinical trials, medical research organizations prepare their findings and present them to the regulatory body. In a thorough examination, if the regulatory body found that a healthy practice can be followed in the treatment of disease then it sends recommendations in the health domain with considering government concerned department. Once treatment is well-accepted then it takes the shape of a smart contract. Patients and doctors are bound to such smart contracts if they follow any such procedure. In another scenario, a smart contract is possible for every person involved in clinical trials. This ensures immutable, transparent, fair experimentation and report writing, and fix the responsibilities as well. Fig. 11 shows the blockchain technology-based payment monitoring system in the proposed healthcare system. It has been observed in populated countries (like India) that there are a large number of crime-cases or unethical practices happening with patients in payments. For example, hospitals overcharge from a patient with false claims when a patient goes through his/her treatment through medical insurance. Although there is a procedure well defined in insurance payment cases but hospitals, doctors or middleman knows the loopholes. Thus, malpractices start from patient admission itself. The patient usually wants a better treatment irrespective of financial losses, especially in emergency cases. Thus, a

TABLE 5. Diabetes clinical trial case study.

Sr. No.	Patient Demographics	Presenting Department	Patient History	Management-Investigations	Management Treatment
1	Young 22 years old Caucasian male with Type1 Diabetes Mellitus (Insulin Dependent Diabetes Mellitus)	Presented to Diabetes & Endocrinology Out-Patient Clinic for the Routine follow up	Newly Diagnosed diabetes six months ago. Initially presented with typical Osmotic Signs & symptoms of DM in the form of polyuria, polydipsia and weight loss along with significantly unwell to the Emergency Department.	Since Diagnosis, Regular home blood sugar monitoring via FreeStyle Libre Glucometer with good control of Blood Glucose with treatment. HbA1c evaluation reveals improvement in glycaemic index with the current value of 6.0%	Continue with Basal, Bolus Insulin Regimen including Insulin Lantus once Night and Insulin Novorapid three times with meals. Carbohydrate Calculation regulated Insulin Treatment Healthy Lifestyle and Regular Exercise Sugar Restricted Diet.
2	36 years old male with known Type 1 Diabetes Mellitus for the last 15 Years on regular treatment	Presented to Accident and Emergency Department with Significantly Unwell	Presented with Symptoms of Nausea, Vomiting, and Cough with Yellow Expectorations. Signs and Symptoms Suggestive of Diabetes Complication in form of Diabetes Ketoacidosis with Pneumonia (confirmed diagnosis after Investigation).	Blood tests revealed raised Inflammatory Markers including raised White cell count & CRP) Raised Blood Sugar Levels checked with Pinpricked Glucometer and Lab Blood Glucose Monitoring. Significantly Raised Urinary and Blood Ketones checked with Krone Sticks. Arterial Blood Gas Analysis show Metabolic Acidosis and Diagnosis in keeping with Diabetes keto acidosis	Treated with Intravenous fluids and antibiotics Blood Glucose Control / Diabetes Management with Insulin Sliding Scale Supportive Management – oxygen, fluids, diet and Anticoagulation etc.
3.	60 years old Asian female with known Type 2 Diabetes Mellitus for the last 20 years but is poorly controlled	Presented to the Diabetes outpatient department for routine follow up	For the Diabetes currently on Treatment with 3 Oral Hypoglycaemic Agents including Metformin, Sitagliptin, and Forxiga. 3rd one is added on the last consultation (3 months ago because of poor glycemic control) Another concern raised today was new tingling sensations in the feet at night causing trouble to sleep.	Patient personal Glucometer revealed 76% of the blood sugar reading within the target limits over the last 3 months. Blood test Revealed improvement of HbA1C with the value of 7.6% improved from 9.6% Feet examinations with Monofilament revealed Evidence of Diabetic peripheral Neuropathy.	Continue with current treatment of oral Hypoglycaemic agents For suboptimal glycemic control- referred to Dietitian and Diabetic Specialised Nurse for further education and counseling Started on newer medication for the symptomatic relief of Peripheral Neuropathy. Next, follow up booked to look for further change (Improvement/deterioration)

patient overlooks such expenses. Fig. 11 shows a model of the payment monitoring system with blockchain-technology. Here, patients and hospitals or doctors are bound with smart contracts. There are actuaries placed on the right side. All of the treatments will have standardized medically recommended procedures and clinical trials, and payment such trials and procedures will be well-defined. Every payment, procedure followed, patient's condition, doctor prescriptions, hospital records, support staff activities will be monitored and recorded through IoT and IIoT. In this digital system, where every record is immutable, transparent and accessible from anywhere, the chances of unethical payment practices would be minimal.

To ensure security in the system, lightweight cryptography primitives and protocols are integrated. Lightweight cryptography primitives include lightweight encryption-decryption mechanism, lightweight hashing mechanism, and lightweight trust mechanism [84]–[86]. Here, different variants of lightweight cryptography primitives and protocols are applied that ensure security during the communicational and computational stages of IoT and IIoT networks. Further, the lightweight proof-of-game (PoG) consensus algorithm is integrated among stakeholders to execute the smart contracts and build trust [87], [88]. The lightweight PoG consensus algorithm is a multi-round consensus-building algorithm that increases the system efficiency by reducing the response time. This consensus building-ensure the interoperability of different stakeholders keeping patients in the center. All of these stakeholders are considered as nodes for building consensus and perform to treat the patients through automatic smart contract execution. Thus, the proposed system is effective and secure. The smart contracts designed and integrated with the stakeholder and executed with PoG consensus-building approach are explained in the next section.

V. PROPOSED SMART CONTRACTS DESIGNS AND THEIR ASSOCIATIONS FOR SMART HEALTHCARE SYSTEM

Fig. 12 shows 16-smart contracts (person, hospital, surgeon, scrub, technician, workingStaff, patient, frontDeskStaff, technicalStaff, staff, technologist, administrativeStaff, receptionist, nurse, department) proposed for the smart healthcare system. All smart contract owners are directly or indirectly

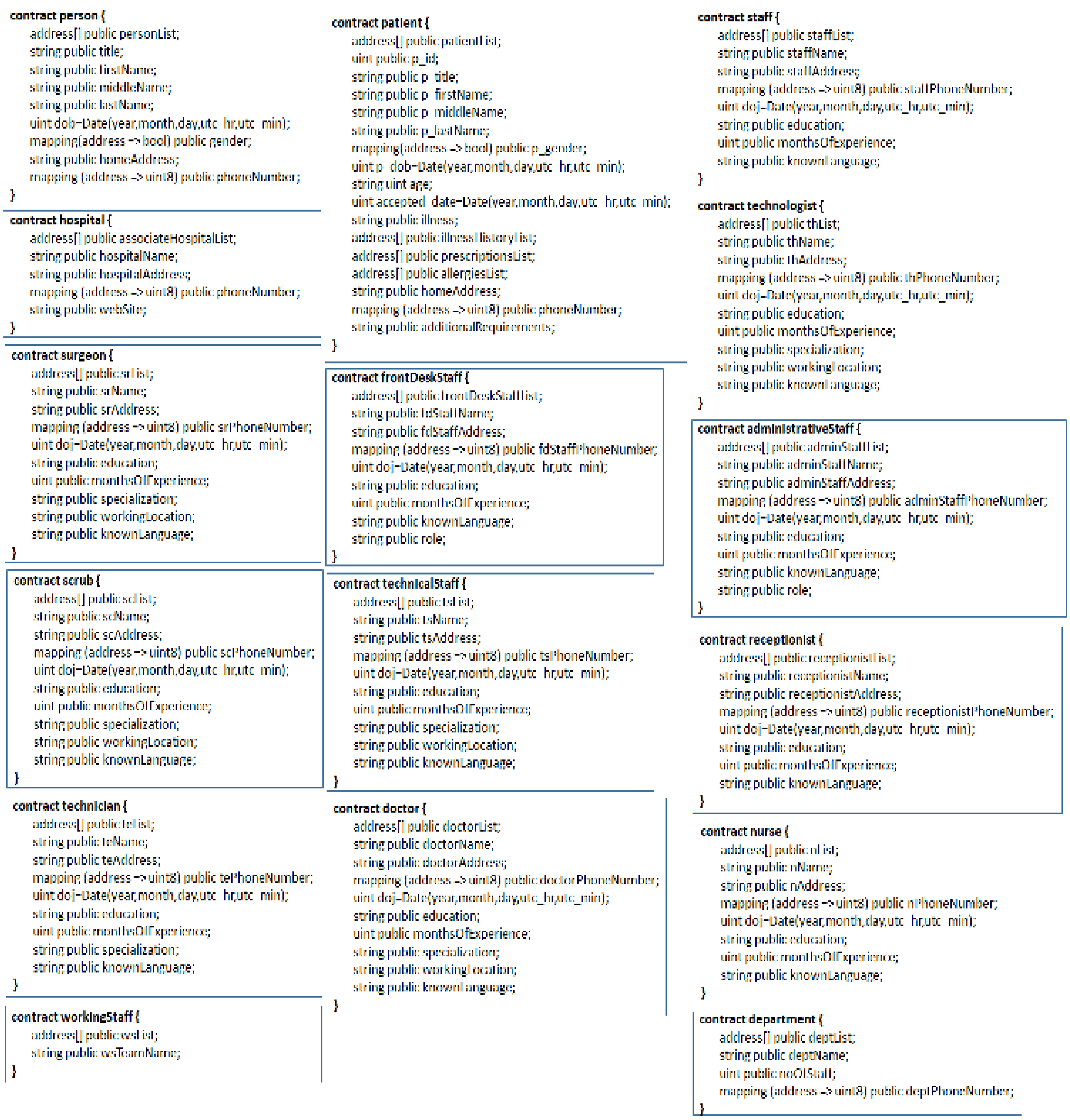

FIGURE 12. List of smart contracts with attributes proposed for the smart healthcare system.

associated (using "is-a" relation) with the hospital as shown in Fig. 13. List and explanation to all smart contract shown in Fig. 12 are as follows:

Person contract stores information about all those persons who are directly associated with the hospital or its related activities. A personList is a list stored in memory to have a permanent and immutable record of persons associated with the hospital even if he/she is discharged or left the job. Besides, a person's associated information like title, first name, middle name, last name, date of joining, gender residential address, and phone numbers are stored as well. Fig. 14 shows the functions defined in person smart-contract. Here, setStatus() functions set person's data and job_rating() function rate the services of hospital members whereas, job_rating() inherited to patient smart-contract is used for feedback.

Hospital contract stores information about hospital-related activities. An associateHospitalList is a list stored in memory to have a permanent and immutable record of the same hospital chains. Additionally, basic hospital information like hospital name, address, phone number, and website are stored as well. Fig. 14 shows the smart-contract functions. Here, setStatus() is used by the owner of the hospital only to finalize hospital members. Further, functions like setStatus(), registerPatient(), validatePatient(), executeTreatment() and preparereport() are all job defined in hospital smart-contract.

setStatus() decides the needs of the hospital, registerPatient() and validatePatient() are functions to decide whether

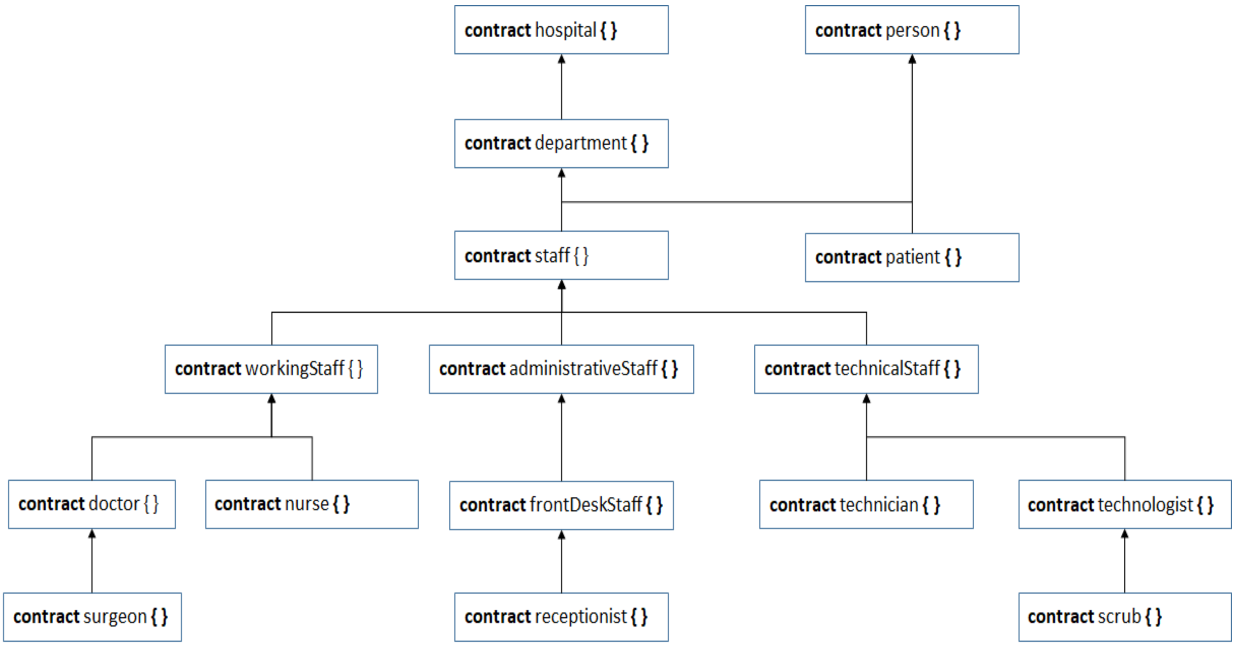

FIGURE 13. Proposed Smart contracts inheritance and associations in the smart healthcare system.

treatment can be execute and credentials can be verified or not. If possible then executeTreatment() runs the diagnosis part. Finally, the patient report is prepared in preparereport

Surgeon is an important smart contract and all of the information associated with this contract is very important because a specialized and experienced doctor is not easily available. Even if they are available it is usually very difficult for a patient to search them. This contract will make a permanent entity of specialized doctors in the blockchain network and it would be convenient for everyone. A list of surgeons is stored permanently using memory mapping in srList variable. Apart from this information, the surgeon's name, address, phone number, date of joining, education, months of experience, specialization, working location (both hospitals and home) and known communication languages are stored. Various functions in this smart contract are:

setStatus(), operation(), specialization(), putPatientonMedication(), verifyReport(), setSalary() and getSalary Surgeon information is set through setStatus() function, operation details are stored in operation() function, specialization() function return the surgeon specialised area, surgeon can put patient on medication using putPatientMedication() function, surgeon can set or verify the reports using preparereport() and verifyReport() functions, surgeon negotiate or get salaries for their services using setSalary() and getSalary() functions.

Scrub is a surgical technologist. This member helps the doctor during surgeries in operation theatre or handle the patient if the doctor is unavailable. Thus, their presence and necessity in the hospital are highly recommended. Like a doctor, scrub's name, residential address. phone number, date of joining, education, months of experience, specialization, working location, and known communication languages are stored in the smart contract system. Various functions in this smart contract are: setStatus(), services(), job_rating(), setSalary() and getSalary() as shown in Fig. 14. The functions like setStatus(), setSalary() and getSalary() have same functionalities as defined for other. A function that makes this smart-contract different from other is services and job_rating() because services of the scrub are totally different accordingly job ratings are decided.

Technician is a technical but non-medical staff member in the hospital. In a medium to large infrastructure-based hospital, a technician is permanent members of the hospital. Different and multiple sets of technicians are required daily to operate a hospital. Thus, their list is stored in teList variable. Apart from this information, their names, residential addresses, phone number, date of joining, education, months of experience, specialization area and known communication languages are stored in the smart contract system. It has been observed that small scale hospitals ensure technician availability on-call rather have them as a permanent employee. Various functions in this smart contract are: setStatus(), services(), job_rating(), setSalary() and getSalary() as shown in Fig. 14. All functions are self-explanatory now.

Most of the properties of working Staff smart contracts are inherited from doctors and nurses. Apart from inherited features, this smart contract stores a list of currently working staff members in wsList and team name in wsTeamName. In the proposed system doctors and nurses are considered as working staff members. Whereas, all technical staff members are also working members but their operations are not continuous and they are called from their departments as and when required. Various functions in this smart contract are:

```
contract person {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function job_rating() public{ }
}
```

```
contract patient {
constructor() public{ }
function setData() OnlyOwner public{ }
function getTreatment(address _patient) public { }
function collectReport() public{ }
function medication() public{ }
}
```

```
contract staff {
constructor() public{ }
function setData() OnlyOwner public{ }
function job_rating(address _staffMember) public{}
function setSalary() OnlyOwner public{ }
}
```

```
contract hospital {
constructor() public{ }
modifier OnlyOwner{ }
function setStatus() OnlyOwner public{ }
function registerPatient(address _patient) public { }
function validatePatient(address _patient) view public returns(bool) {}
function executeTreatment(address _patient) public view returns(uint){ }
function preparereport() public{ }
}
```

```
contract frontDeskStaff {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function job_rating() public{ }
function services(address _patient) public{}
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
}
```

```
contract surgeon {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function operation(address _patient) public{}
Function specialization( ) view public returns(String) {}
function putPatientonMedication(address _patient) public{}
function verifyReport() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
}
```

```
contract technologist {
constructor() public{ }
modifier OnlyOwner{ }
function setStatus() OnlyOwner public{ }
function treatment(address _patient) public{}
function verifyReport() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
function job_rating() public{ }
}
```

```
contract scrub{
constructor() public{ }
function setStatus() OnlyOwner public{ }
function services(address _patient) public{ }
function job_rating() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
}
```

```
contract technicalStaff {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function services(address _patient) public{}
function job_rating() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
}
```

```
contract administrativeStaff {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function services() public{}
function job_rating() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
}
```

```
contract technician {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function services(address _patient) public{ }
function job_rating() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
}
```

```
contract receptionist {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function services(address _patient) public{}
function job_rating() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
}
```

```
contract nurse {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function services(address _patient) public{}
function job_rating() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
function monitorPatientonMedication(address _patient) public{}
}
```

```
contract department {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function teams() public{ }
}
```

```
contract doctor {
constructor() public{ }
function setStatus() OnlyOwner public{ }
function operation(address _patient) public{}
function putPatientonMedication(address _patient) public{}
function verifyReport() public{ }
function setSalary() OnlyOwner public{ }
function getSalary() public{ }
}
```

```
contract workingStaff {
constructor() public{ }
function workTime() OnlyOwner public{ }
function attendance() public{ }
}
```

FIGURE 14. **List of smart contracts with functions proposed for the smart healthcare system.**

workTime() and attendance() as shown in Fig. 14. All staff members working timings and attendance are inherited from this smar-contract using worktime() and attendance() functions.

Patient is another important smart contract in the system. In order to have permanent and immutable records, this contract stores all patients treated in a hospital at a memory location. Apart from this information, information like patient id, patient title, first name, last name, gender, date of birth, age, date of admission, illness, illness history in a form of a list, medical prescriptions for the present diagnosis in the form of a list, list of allergies from anything (food, cloth, medicine etc.), residential address, phone number, and any special requirements during treatment (if any). Various functions in this smart contract are: setData(), getTreatment(), collectReport() and medication() as shown in Fig. 14. Patient data is set in system using setData(), the patient gets his/her treatment after executing getTreatment() function, patient can collect report in collectReport() and take medicines recommended in medication() function.

Front desk staff contract is to handle patients or their family members to have quick, appropriate doctor consultations, and hospital's processes and procedures. As front desk staff have both medical and non-medical background staff, a list of both of these staff members is prepared in frontDeskList variable. Various functions in this smart contract are: setStatus(), job_rating(), services(), setSalary() and getSalary() as shown in Fig. 14.

Technical staff contract is to handle all types of technical staff members (both medical and non-medical) in a hospital. A list of each of these staff members is stored in tsList variable. Additionally, name, residential address, phone number, date of birth, education, months of experience, specialization/expert-domain, working location and known communication language information are stored in blockchain network using a smart contract as well. Both technicians and technologists can be a technical staff member. Thus, properties from both technicians and technologists are inherited in technical staff smart-contract. Various functions in this smart contract are: setStatus(), services(), job_rating(), setSalary(), getSalary() as shown in Fig. 14.

Staff contract inherits properties from working staff, administrative staff, and technical staff members. It collects lists of all types of staff members and stores with himself in staffList variable. Additionally, staff name, residential address, phone number, date of joining, education, months of experience and known communication languages are also inherited and store here. Hospitals and its specialized department do transactions with staff smart-contract rather than executing an individual transaction with each of these the smart-contract. Various functions in this smart contract are: setData(), job_rating() and setSalary() as shown in Fig. 14.

Technologist contract is designed for those staff members who have a medical background and helps the doctor in operation theatre or patient in the ward or private room. A technologist is having a medical background and its information like name, residential address, phone number, date of joining, education, months of experience, specialization, working location and known communication language is stored in smart contract variables to have a better experience and timely respond to events. This smart contract is necessary to have proper lab report records as well. Lab records if not prepared properly then it can harm the patient a lot. Thus, it is necessary to have a responsibility fixed with transparent and immutable records. In conclusion, this smart-contract would be very beneficial to such scenarios. Various functions in this smart contract are: setStatus(), treatment(), verifyReport(), setSalary(), getSalary() and job_rating() as shown in Fig. 14.

Administrative staff contract is to monitor all transactions performed with front desk staff members like a receptionist. The administrative staff takes the insurance claim requests as well. Information like admin staff list, name, residential address, phone number, date of joining, education, months of experience, known communication languages and role are stored in the blockchain network. Some of this information is helpful in tracking the transactions before with them for fair and furious hospital services. Various functions in this smart contract are: setStatus(), services(), job_rating(), setSalary() and getSalary() as shown in Fig. 14.

A receptionist is the first non-technical person with whom a patient or associates interact to have the required information. As healthcare service is 24×7 service in medium to large scale hospitals, a list of receptionists is necessary along with the name, residential address, phone number, date of joining, education, months of experience and known communication languages. The receptionist is part of the front desk team. Thus, most of the properties of receptionists are inherited in front desk staff to keep track the number of daily queries raise to have any type of treatment. Various functions in this smart contract are: setStatus(), services(), job_rating(), setSalary() and getSalary() as shown in Fig. 14.

Nurse contract is for supporting and working for staff in the hospital. Patients and doctors regularly have transactions (medical teamwork) with the nurse. Thus, important information like name, date of joining, phone number, residential address, education, experience, and known communication languages are important information stored in blockchain networks. Various functions in this smart contract are: setStatus(), services(), job_rating(), setSalary(), monitorPatientonMedication() and getSalary() as shown in Fig. 14.

Department inherits properties from staff as most of the transactions (medical jobs) are executed in a team of staff members. Thus, the department constitutes teams and they execute transactions. In this smart contract important information like department name, the number of staff members, department phone number and alist of staff members is stored. Various functions in this smart contract are: setStatus() and teams() as shown in Fig. 14. These smart contracts are executed over remix Ethereum with free user accounts that have 100 default Ethers for executing and exchange among contracts. To secure the smart contracts and associated functionalities, Vulnerable(), UntrustedAction(), TrustedAction(), and DoSWithGas() are designed. Vulnerable() smart contract cross-check with externals calls, identify malicious codes, and re-direct the action flow if required. Here, external calls may interrupt and redirect the action flow as well. Thus, Vulnerable() smart contracts take care of such actions. TrustedAction() and UntrustedAction() smart contracts are executed to avoid the unexpected risks and errors. Here, external contracts may execute unwanted actions in a smart contract. To avoid such actions, each activity is monitored using trusted and untrusted actions. The contract verifies whether any change in state or external call violates the smart contract interaction pattern or not. If it does so then the action is noticed and it is put in the category of a known attack. DoSWithGas() smart contact handle the cases when a node refuses to take action after action verification then a fixed gas amount is reducted. Formally, If an activity (S, o, a) is executed with smart contract S with action a and interaction o then external call assertion $A(S)$ with $o \rightarrow SxS \rightarrow S$ and $a \in S$. Now interaction o is validated if it satisfies $A(S)$: $F_1 * F_2$ with equation (1).

$$\{S_{f_1} o S_{f_2} | S_{f_1} o S_{f_2} \text{ is defined and } S_{f_1} \in F_1 \text{ and } S_{f_2} \in F_2\} \quad (1)$$

Here, F_1 and F_2 are functions in S. An action from F_1 to F_2 is formally defined as $F_1 \rightarrow F_2$ with verification defined in equation (2).

$$\{S | \forall S_{f_1} \cdot S o S_{f_1} \text{ defined and } S_{f_1} \in F_1 \text{ and } \mathrm{So} S_{f_2} \in F_2\} \quad (2)$$

Smart contract interaction in memory is a finite function of pre-defined length and data type with a disjoint function domain. After the interaction, it becomes a single set $\{f\}$ that maps two smart contracts defined elsewhere. The interaction of two smart contracts is considered to be secure if the variables and quantifiers considered in functions extend the pointwise semantics defined in equation (1) and (2). The maximum communication and computational costs in terms of gate equivalents of applying a security check are computed as 610 GEs and 720 GEs. Overall, the security of the smart contract is achievable within 1000GEs if parallel and distributed actions are allowed to be executed.

Algorithm 3 Staff Activity Cycle

Premises: Same as algorithm 1 and algorithm 2's premises. Additionally, $S^l_{working\_staff}$ is l^{th} working staff set consisting of residential doctors, technologists, and nurses, $S^l_{administrative\_staff}$ is l^{th} administrative staff set consisting of front desk staff and receptionists, and $S^l_{technical\_staff}$ is l^{th} technical staff set consisting of technicians (contractual or permanent employees) and technologists (including scrub).
Goal: To coordinate with department activities, and support surgeons and doctors in treatment.

1. Function Working_staff_activity_cycle()
   a. **While** Patient treatment is over **do:**
   b. **If** $U_i \in S^l_{working\_staff}$ **do:**
   c. **If** $U_i^{address}$ is valid **then:**
   d. **If** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} are satisfactory **then:**
   e. **If** the number of U_i required in $T^j_{D_i}$ is less than a threshold **then**
   f. **Assign** U_i to in $T^j_{D_i}$
   g. **Treat** patient
   h. **Verify** patient reports preparedness
   i. **Else**
   j. **Treat** patient
   k. **Verify** patient reports preparedness
   l. **Else**
   m. **Instruct** U_i to go for self or specialized treatment
   n. **Update** EMR, HER and PHR records
   o. **Else**
   p. **Register** $U_i^{address}$
   q. **Update** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} records
   r. **Else**
   s. **Fetch** U_i records
   t. **Register** U_i in $S^l_{working\_staff}$
   u. **End While**
2. Function Administrative_staff_activity_cycle()
   a. **While** Patient treatment is over **do:**
   b. **If** $U_i \in S^l_{administrative\_staff}$ **do:**
   c. **If** U_i is receptionist **then:**
   d. **Register** Patient
   e. **Inititate** doctor-patient trial
   f. **Else If** U_i is a ward or recovery room person and avilable **then:**
   g. **If** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} are satisfactory **then:**
   h. **Assign** U_i to patient
   i. **Move** patient to ward or recovery room
   j. **Else**
   k. **Instruct** U_i to go for specialized treatment
   l. **Update** EMR, HER and PHR records
   m. **Else**
   n. **Register** $U_i^{address}$ in receptionist or front desk staff
   o. **Update** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} records
   p. **Else**
   q. **Fetch** U_i records
   r. **Register** U_i in $S^l_{working\_staff}$
   s. **End While**
3. Technical_staff_activity_cycle()
   a. **While** Patient treatment is over **do:**
   b. **If** $U_i \in S^l_{technical\_staff}$ **do:**
   c. **If** U_i is technician **then:**
   d. **If** $U_i^{address}$ is valid **then:**
   e. **If** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} are satisfactory **then:**
   f. **Assign** technician to fix all infrastructure issues
   g. **Else**
   h. **Instruct** U_i to go for self or specialized treatment
   i. **Update** EMR, HER and PHR records
   j. **Else**
   k. **Register** $U_i^{address}$ in receptionist or front desk staff
   l. **Update** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} records
   m. **Else if** U_i is technologist **then:**
   n. **If** U_i is scrub **then:**
   o. **If** the number of U_i required in $T^j_{D_i}$ is less than a threshold **then**
   p. **Assign** U_i to in $T^j_{D_i}$
   q. **Treat** patient
   r. **Verify** patient reports preparedness
   s. **Else**
   t. **Treat** patient
   u. **Verify** patient reports preparedness
   v. **Else**
   w. **If** the number of U_i specialization is required in $T^j_{D_i}$ and the number of U_i is less than a threshold **then**
   x. **Assign** U_i to in $T^j_{D_i}$
   y. **Treat** patient
   z. **Verify** patient reports preparedness
   aa. **Else**
   bb. **Treat** patient

cc. **Verify** patient reports preparedness
dd. **Else**
ee. **Register** $U_i^{address}$
ff. **Update** U_i^{EMR}, U_i^{EHR} and U_i^{PHR} records
gg. **Else**
hh. **Fetch** U_i records
ii. **Register** U_i in $S^l_{working\_staff}$
jj. **End While**

VI. PROPOSED SIMULATION-OPTIMIZATION APPROACH

In this section, the simulation-optimization approach applied to the smart healthcare system is explained in detail. As discussed earlier, a smart healthcare system has many subsystems including drug traceability systems, clinical trial records, and research analytical system, healthcare payment systems etc. In this work, a methodology for patient experiences starting from admission to discharge with healthcare 4.0 trends has been proposed using simulation optimization. The simulation-optimization is required for the selected problem statement because it handles unusual or abnormal conditions/challenges in a dynamic way. For example, the availability of a specialized doctor in an emergency, treatment success or failure rates to non-medical persons like a patient, availability of patient's medical records as and when required at any place over the planet etc. Here, simulation-optimization is beneficial to IoT and IIoT network performance measurement and optimization as well. This way the detailed network and smart healthcare system data analytics would be much easier and helpful in improving the overall system performance. The statistical simulation-optimization approach applied to the smart healthcare system and IHIoT network are explained as follows:

A. SMART HEALTHCARE SIMULATION-OPTIMIZATION SYSTEM

In this section, a formal simulation optimization-based objective function for the smart healthcare system is designed.

In a smart healthcare system, all integrated systems are considered to be functional with the criteria C having n-input parameters $(i_1, i_2, \ldots, i_n)$ if the objective function $C = f(i_1, i_2, \ldots, i_n)$ prioritize integrated system working in the first order and all sub-systems performance in the second order. Here, two evaluations (integrated system working and sub-system performances) are considered to evaluate the performance of the proposed simulation-optimization approach and analyze the results. However, the proposed approach can be integrated with other possible scenarios like blockchain network integration with healthcare, IoT and IIoT integrated evaluations etc. In an integrated system working, sub-systems integrity can be evaluated with minimization and maximization criteria functions as:

$$(minimize\ C = f(i_1, i_2, \ldots, i_n))) \leq I \leq (maximize\ C = f(i_1, i_2, \ldots, i_n))) \quad (3)$$

Here, I is the acceptable sub-systems integrity score. In Euclidean space, equation (3) can be re-written for independent variables and associated dependent variables in n-dimensions as follows:

$$f(i_n) \leq I \leq f(i_n) \quad \text{for } i_n \in E^n \quad (4)$$

Now, considering the multi-variate simulation-optimization approach in consideration, various possible scenarios are formulated as: (i) healthcare 4.0 trends and blockchain integrated drug traceability, (ii) healthcare 4.0 trends and blockchain integrated clinical trial system, and (iii) healthcare 4.0 trends and blockchain integrated healthcare payment system.

1) HEALTHCARE 4.0 TRENDS AND BLOCKCHAIN INTEGRATED DRUG TRACEABILITY SCENARIO

In the present scenario, a large number of counterfeit drugs are available in the market that can lead to loss of lives in slow poison. In healthcare 4.0 trends with blockchain, drug supply chain integrity can be verified easily with the help of a unique identification number, an independent drug supply ledger for government-approved drugs, drug research records and patents storage over blockchain, and the smart contract between suppliers, distributor, and purchaser. This scenario will help all stake-holder in the smart healthcare system to have (ii) clear visibility over drug contents and decision-making capability in critical cases, (ii) reduce cost, (iii) loss of harmful counterfeit drugs, and (iv) identification and legal actions over fake pharmaceutical drugs and companies. Healthcare 4.0 trends and blockchain integrated drug traceability in supply chain management can be optimized using the following objective function inputs:

1) $f(i_1)$ is an optimization function to record the drug supply between any two hands. Let S_{ij} represents the drug supply from l^{th} supplier to m^{th} supplier. Now, a minimum and maximum number of suppliers should be defined in such a way that the total drug cost should not exceed P_{Total}. In result, total drug cost from source to the final consumer can be computed as

$$P_{Total} = \sum_{l=1}^{T_1+T_2} \sum_{m=1}^{T_1+T_2} P_{lm} S_{lm} \quad (5)$$

Here, T_1 and T_2 represents the total number of sources and intermediate drug suppliers in the drug supply system. Further, blockchain and industry 4.0 based constrained formalization over this objective function that can be formalized as:

- *Block creation and insertion at every supplier:* In this constraint, it is made mandatory at every supplier side to create a block of the drug at its entry and out from his storage. Information like drug identification (b_1), purchasing supplier (b_2), selling supplier (b_3), timestamp (b_4), the government-approved manufacturing company $((b_5)$ etc. should have their blocks and whenever there is any transaction, information is stored in the blockchain network. Finally, the input set to the optimization function becomes $i_1 = \{b_1, b_2, b_3, \ldots\}$.

- *Data verification before creating* a *block and adding the block in* a *ledger:* In the complete smart healthcare system, there are bodies well defined (as a medical board, actuaries, government, court etc.) who look after the process transparently. Thus, they will be able to verify the records of every block having anomalies using $\mathrm{V}(b_i)$ verification function. All bloc's verifications result to a positive value in input verification i.e. $\mathrm{V}(i_1)$ will be positive.
- *Minimu and Maximum drug delivery that meets the pharmacy requirements:* In this constraint, the maximum drugs allowed in $^{\mathrm{lth}}$ delivery from all $^{\mathrm{mt}}$ h supply point should be equal to all pharmacy requirements $O_i()$ i.e.

$$\sum_{l=1}^{T_3} D_{lm} = O_i \text{ Where, } \quad m \in \{1, 2, \ldots, T_4\} \tag{6}$$

Here, D_{ij} is the drug delivery count from l^{th} point to m^{th} point. T_3 and T_4 are the total drug delivery points and vehicles to deliver drugs respectively.

2) $f(i_2)$ is an optimization function to record the clinical trials. Like the drug supply system, drug clinical trails are equally important. There are many falsified trials with no or minimal medicine effects observed in trials but medicines are available in the market without government approval. It would be very difficult to ensure the tracking of such drugs and validate their clinical trails because trial companies are not traceable. Various objective function that can be formalized in this case include (i) block creation and insertion for every stakeholder (lab staff, company, instrument provider, chemical salt provider etc.), (ii) data verification before a pharmacy accept to sell any medicine, (iii) minimum and maximum drug effects in its trials and specifications, and (iv) similar salt medicine minimum, average and maximum cost comparisons.

2) HEALTHCARE 4.0 TRENDS AND BLOCKCHAIN INTEGRATED DOCTOR TREATMENT SYSTEM

Doctor treatment system is equally important in the smart healthcare system. The proposed system should able to ensure that the doctor follows the best practices and adhere to the Hippocratic oath. Also, the objective function required to be considered in this case includes: (i) minimum and maximum successful or failure treatment allowed after certification, (ii) minimization and maximization of reward for successful, innovative and excellent treatments, (iii) minimum and maximization of processes instructions followed in treatment, and (iv) minimum and maximum set of instructions need to be given to the patient after treatment.

3) HEALTHCARE 4.0 TRENDS AND BLOCKCHAIN INTEGRATED PAYMENT SYSTEM

Payment scenario is discussed earlier as well and it is observed that blockchain technology in the healthcare payment system is highly recommended to control various costs involved at different levels. Thus, the objective functions required in this use-case involve (i) minimum and maximum cost standardization for every possible treatment, (ii) minimization of costs involved in treatment through multiple payment methods (insurance, cash, sponsored etc.), and (iii) arrangement of minimum or maximum non-government sponsored organizations to support treatment for economically weaker section patients.

Algorithm 4 Healthcare Insurance Activity Cycle

Goal: To present the simplified cash and cashless insurance activities.

```
    If treatment is cashless then:
        Patient initiate pre-authorization before
        hospitalization
        If claim registered by alliance then
            Approval letter issued to hospital, patient or
            both
            Produce member identification and get
            hospitalized
            Get Treatment and discharge
        Else
            Go for cashless treatment
            Break
        End If
Else
        Patient gets hospitalized
        Patient and hospital apply for pre-authorization
        form within the specified time of hospitalization
        If claim registered by alliance then
            Get Treatment
            Collect bills and discharge
        Else
            An insurance claim is rejected
            Exit
        End If
        Produce bills and medical documents to the
        alliance
        If alliance verify records then
            Claim processed and amount transferred to
            patient account
        Else
            An insurance claim is rejected
            Exit
        End If
    End If
```

B. IoT AND IHIoT SIMULATION-OPTIMIZATION SYSTEM

Like smart healthcare simulation-optimization, simulation-optimization of quality of service in backbone smart healthcare network networks (IoT, IIoT, and IHIoT) should be required to provide timely, effective and efficient results. To optimize the quality of service, various use-cases and objective functions considered for the proposed system include:

1) *Bandwidth utilization*: network services should be uniformly available throughput the operation cycle to every entity in the network. To ensure these various objective functions include (a) minimum and maximum network bandwidth utilization per entity, (b) identification of critical or no-use bandwidth entities, (c) uneven bandwidth utilization identification for attack scenarios and (d) minimum and maximum bandwidth utilization allowed in scenarios where there are slow-down in services due to uncontrolled scenario.
2) *Bandwidth-delay product*(BDP): various objective function in this category include (a) network services should include BDP per connection and per network for every entity in the network, (b) BDP monitoring for attack analysis, and (c) minimum and maximum BDP allowed in scenarios where there are slow-down in services due to uncontrolled scenario.
3) *Inflow and outflow per entity*: various objective function in this category include (a) minimum and maximum inflow and outflow rate per entity (device or network) allowed to communicate in a network, (b) minimum and maximum packet scanning access control required to monitor inflow and outflow traffic per entity, and (c) minimum and maximum indices identification, measurement, and analysis for inflow and outflow traffic for network monitoring and attack analysis.

Algorithm 5 shows the local-global simulation-optimization approach applied to improve block performance in both healthcare and IHIoT networks. In this approach objective function computations and error-deviation are computed to identify local and global optimum solutions.

Algorithm 5 Proposed Local-Global Simulation-Optimization Approach

---

Premises: Let L_0, $L_{local\_optimum}$, $L_{global\_optimum}$ and $L_{desired}$ are the initial, local optimum, global optimum and desired performance result parameters respectively. $F_{initial}$, $F_{desired}$ and F_{final} are the initial, desired and final objective function having n-blocks inputs $i_n \in \{b_0, b_1, b_2, b_3 \ldots b_n\}$. Here, t is the total number of local regions.

Goal: To collect immutable and necessary network records and identify the input (i_k) and objective function F values such that the considered objective function with optimal input gives the best local or global optimum solution.

1. **While** *(solution* **not** *satisfactory***or** *trail* **not** *possible)*
2.   **Execute** Local_Optimization_Procedure()
3.   **Execute** Gobal_Optimization_Procedure()
4. **End While**
5. **While** *(variations* **is not***minimized*
6.   **Execute** Convergence_Procedure()
7. **End While**
8. **While** *(solution* **not** *satisfactory***or** *trail* **not** *possible)*
9.   **Execute** Gobal_Optimization_Procedure()
10. **End While**

Procedure 1: Local_Optimization_Procedure()

1. **Initialize** $l = 0$
2. Randomly select a block for optimization b_l
3. **Initialize** local optimum result variation list to NULL i.e. $L^t_{local\_optimum} = []$
4. **Compute** initial objective function variation i.e. $F_{initial} = f\ (i_{ininital})$, Here, $i_{ininital} \in \{b_0, b_1, b_2, b_3 \ldots\}$
5. Select a local region (r) of block performance having n-inputs i.e. $\in \{1, 2, 3, \ldots, n\}$
6. **For each** local region t $\in r$:
7.   **Compute** performance result variation as $\Delta L_t = |L^{old}_t - L^{new}_t|$
8.   **Append** ΔL_t to $L^T_{local\_optimum}$
9.   **Compute** $L_t = L_{t-1} + \Delta L_t$
10.   **While** $L_{local\_optimum} \neq L_{desired}$:
11.   Randomly select an 's neighbor whose performance measure is close to desired value
12.   **While** neighbor(r) $\in$ 1, 2, 3, ..., n:
13.   **If** the performance of neighbor(r) is higher than the upper threshold or lower-than lower threshold **then**
14.   **Remove** neighbor(r) from its current position and insert at the end for re-evaluation
15.   **Else**
16. $L_{local\_optimum} = L_t$
17.   **End If**
18.   **End While**
19. $l = l + 1$
20.   **End While**
21. **End For**
22. **Compute** F_t = fL_t()
23. **Return** ($L_{local\_optimum}$, F_t)

Procedure 2: Global_Optimization_Procedure()

1. **Initialize** $l = 0$
2. Randomly select a block for optimization b_l
3. **Initialize** global optimum result variation list to $L^T_{global\_optimum} = [L^1_{local\_optimum}, L^2_{local\_optimum}, \ldots, L^t_{local\_optimum}]$, Here, $T \in \{1, 2, 3, \ldots, \}$ is set of local regions
4. **Compute** initial objective function variation i.e. $F_{initial} = f\ (i_{ininital})$, Here, $i_{ininital} \in \{b_0, b_1, b_2, b_3 \ldots\}$
5. **For each** local region t $\in T$
6.   **Verify** L_t and compute $\Delta L_t = L^{old}_{local\_optimum}$ -$L^{new}_{local\_optimum}$
7. **End For**
8. **For each** local region t $\in T$
9.   **If** ΔL_t is negligible **then**
10. $L_{global\_optimum} = L_t$
11.   **End If**
12. **End For**
13. **Compute** F_t = fL_t()
14. **Return** ($L_{global\_optimum}$, F_t)

Procedure 3: Variable_Convergence_Procedure(

1. **If** $F_t \leq F_{desired}$ and/or $\Delta L_t \leq \Delta L_{desired}$:

TABLE 6. Simulation parameters for the smart healthcare system.

Parameters	Values
Simulator	JaamSim
Simulator System Configuration	Intel(R) Core(TM) i5-7200 CPU @ 2.50GHz, 8.00 GB RAM,1 Gbit/s network connection, 512GB SSD
FirstBlockArrivalTime	0 second
InterBlockArrivalTime	10, 20, 30, 40, 50, 60 seconds
Cryptocurrency	Ethereum
Block Working StateList	[Created Wait Mined]
TransactionsPerBlock	Less than and equal to 1000
Average Actual Transactions to Simulated Transactions Error Rate	0.41%
BlockAttributeAssignmentList	Block Address
Transactions StateList	[Create Write Read]
Maximum patient handling per doctor at a time	1
Minimum-Maximum surgeon associated to one patient	1-3
Minimum-Maximum technologist associated with one patient	1-4
Minimum-Maximum nurses associated with one patient	1-3

2. return ($L_{global\_optimum}$, F_t)
3. **Else**
4. **Execute** Local_Optimization_Procedure()
5. **Execute** Global_Optimization_Procedure()
6. **End If**

VII. SIMULATIONS

This section presents the healthcare 4.0 trends based smart healthcare system simulation using JaamSim [89] and JSImgraph Simulators [90]. Two different simulators with different simulation scenarios are considered for simulation to analyze the overall system functionalities in detail. JaamSim is a free and open-source simulation having interactive drag-and-drop, variable input statistical models, analysis model and output dataset creation capabilities. Section VII (A) explores the JaamSim simulator's simulation to test overall system integrity and evaluate the blockchain network performance statistics. Section VII (B) presents the JSImgraph simulations to analyze the internal functionalities (especially the performance of block miners, block transaction capabilities, block storage capacities etc.) of the blockchain-based smart healthcare system. Detailed simulations are explained in the following sub-sections.

A. SIMULATION USING JaamSim SIMULATOR

JaamSim is an open-source simulation and gives the flexibilities to simulate smart healthcare system functions with its graphical objects, probability distribution models, generalized objects flow, resource objects, process flows, calculation statical objects, statistical fluid objects and submodel object creation provisions. Table 6 shows the simulation parameters used to design, execute and analyze the smart healthcare system parameters and results. In this simulation, FirstBlockArrivalTime and InterBlockArrivalTime are set to simulate the block and blockchain network's functionalities as these are mandatory input parameters. A virtual simulation of Ethereum cryptocurrency is considered. The average actual transactions to a simulated transaction error rate is considered to be 0.41% after analysis. Instead of assigning memory to block and its associated transaction, block addresses are mapped to BlockAttributeAssignmentList. Random variations of doctors, surgeons, itechnologists, and nurse staff associated with the patient are considered for experimentation and simulation. All those performance parameters are considered for evaluation and analysis that are importantly considered in the ethereum network. For example, block size variation, block utalization, smart contract execution time, and transaction executed per block helps in evaluating the network functionalities. Similarly, simulation of gas limit, average hash rate, patient handling, block time variation for different stakeholders helps in understanding the amount and authenticity of work done. Fig. 15 shows the execution of the JaamSim model created in Fig. 3. This model is to test the functionalities of the local interconnected smart healthcare system with blockchain record-keeping capabilities. The execution includes patient admission in the hospital to discharging with medication prescriptions and follow-ups suggestions. Initially, exponential patient intake is considered in a hospital having industry 4.0 capabilities. parallel, a blockchain record management process keeps track of all patient data from its network and update it (if any) over regular intervals. Updated information includes patients-doctor associations and treatment details (including patient address, treatment type, medicines prescribed, patient medical history, doctor-patient history etc.). Likewise, all models designed (Fig. 2, Fig. 6 to Fig. 11) are executable. Fig. 16 to Fig. 23 shows the blockchain network performance evaluations and analysis for the proposed and simulated smart healthcare system. The detailed analysis of each of these performance evaluation parameters is as follows:

Fig. 16 shows the Ethereum maximum block size (in terms of Gas value) variations over simulation time for the proposed and simulated smart healthcare system. Instead of measuring

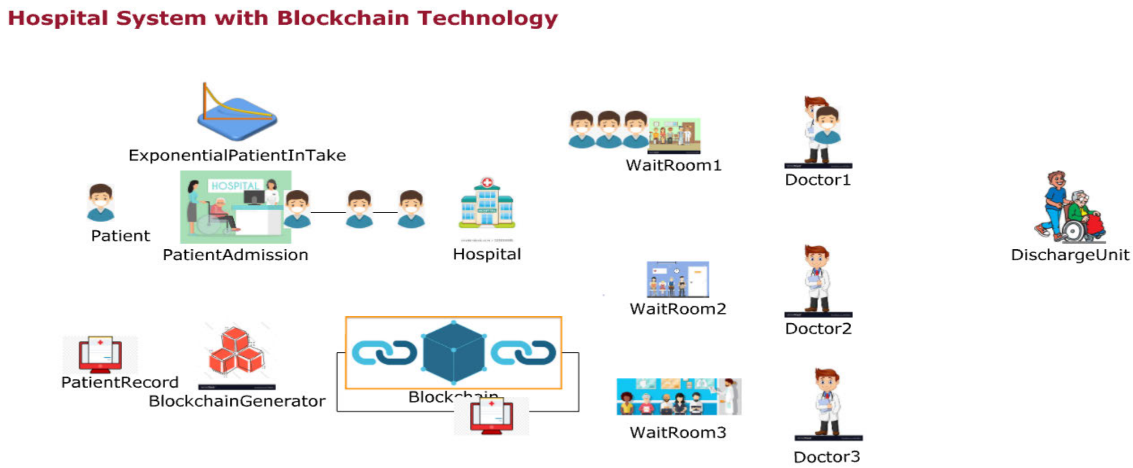

FIGURE 15. Blockchain-based healthcare system in execution.

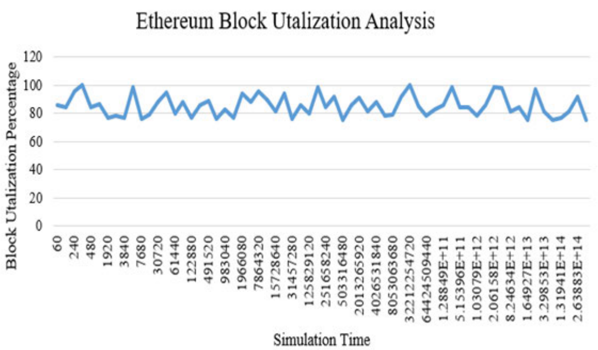

FIGURE 16. Ethereum maximum block size analysis for simulated medical records.

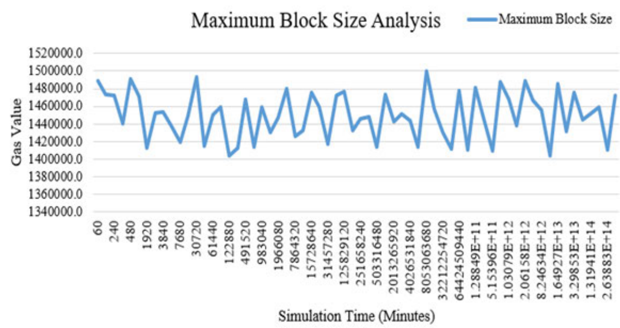

FIGURE 17. Ethereum block utilization variations over the simulation time.

the Ethereum block size in fixed limits (Kb, MB etc.), it is measured as to how many units of gas can be spent per block for healthcare or patient data. As compared to an average block gas limit of around 10,000,000 gas for any type of data, the maximum block size for the proposed system is found to be varying within a range of 1400000 to 1500000 gas limit. There are two types of gas limits considered in general size evaluations: block size gas limit and transaction size gas limit. Large block size is interpreted as the amount of space required to create and store the Ethereum blockchain would be large. It affects the node over an Ethereum blockchain network in terms of cost and performance. As compared to 10,000,000 gas transactions observed for blind Ethereum block size variations in current times, the proposed system has a much lesser block size [91]. This indicates the performance of the proposed blockchain network as well. Medium-Scale block size will be able to incorporate mandatory data and it will not affect the performance of the network as well. Further, the cost of operating required operations in the blockchain network would also be lesser. Fig. 17 shows the Ethereum block utilization variations over simulation time for the proposed blockchain-based smart healthcare system. As discussed in Fig. 16 that network performance increases with keeping the block size within limits. This can be proved in Fig. 17. It has been observed from various Ethereum network statistics that increasing gas limit decreases the block utilization. On the other hand, Fig. 17 results show that block utilization lies between 70% to nearly 100%. This shows that the proposed network is ideal for the smart healthcare system. Now, the utilization of blocks are on the higher side, as a result, the scalability is a major issue. Thus, other indirect parameters should be taken into consideration for increasing the network size like transaction gas limits, smart contract execution time, uncle and normal block creation and decision processes, controlling transaction rates etc. Fig. 18 shows smart contracts execution time in the simulation. In this work, 16 smart contracts have been designed for executing the functionalities of the smart healthcare system. Fig. 18 shows the execution of all smart contracts integrated through inheritance (as shown in fig. 13). The smart contract execution time varies with variation in block size (measured in terms of Gas value). It increases linearly with block size increase. Ethereum remix is used to execute and validate the operations

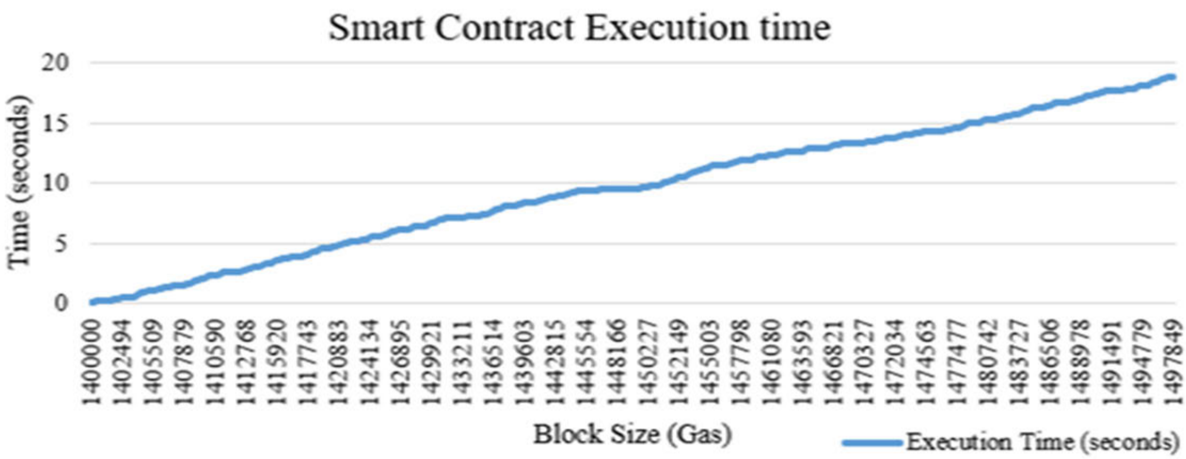

FIGURE 18. Simulated smart contracts execution time with variation in block size.

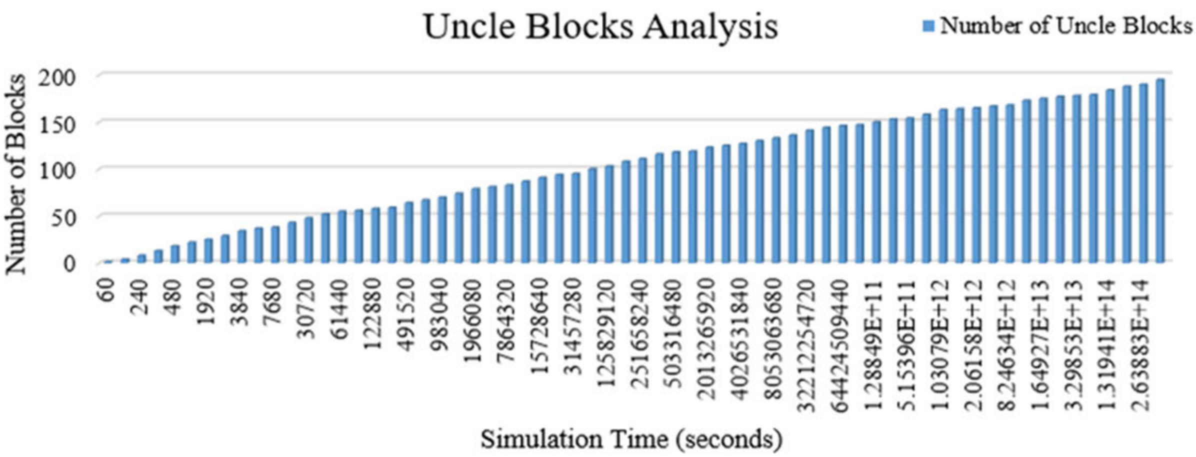

FIGURE 19. Cumulative variations in uncle block creation with simulation time.

of smart contracts. Results show that the designed smart-contracts does not require a large gas limit or gas wastage. Gas wastage is an indication that there are flaws in smart contract design. However, a linear increase in smart contract execution time indicates that the chances of flaws are much lesser. Fig. 19 shows uncle block analysis with variations in simulation time. Uncle blocks are associated with the Ethereum blockchain network, valid block in the networks mined in a regular block mining manner, and compete for blockchain insertion through a consensus algorithm. Uncle blocks are not rejected to be part of the mainstream blockchain network because of blockchain working patterns. However, blockchain is considered to be the part of a growing blockchain network and stores various transactions occurring in the blockchain network. In customized cases, uncle blocks handle network security issues as well. Algorithm 6 explains the uncle block calculations in detail.

Fig. 19 shows the cumulative variations in uncle block creation with simulation time. As the number of newly created uncle blocks are increasing in number, this shows the importance of healthcare blockchain network. Many nodes are completing in the network to insert their block in the blockchain network but did not get a chance because of the challenge issued in a consensus algorithm. Fig. 20 shows the number of transactions executed per block over simulation time. Results show that the maximum number of transactions per block is around 380. Nowadays, the Etherum network supports thousands of transactions per second like financial institutions [91]. However, the average number of transactions per second in the Ethereum network is around 400. Results in Fig. 20 show that the proposed smart healthcare network requires a maximum of 380 (approx.) transactions. This indicates that indirect parameters like gas limits, execution time and network performance can be kept in a feasible range with observed transactions. As compared to other blockchain networks like Bitcoin, Ethereum has a lesser number of transaction and this reduces the chances of scaling [91]. In order to improve the number of transactions per second, sharding is one of the initial steps followed. Sharding can increase the number of the transaction by a few hundred only. In result, other scaling solutions need to

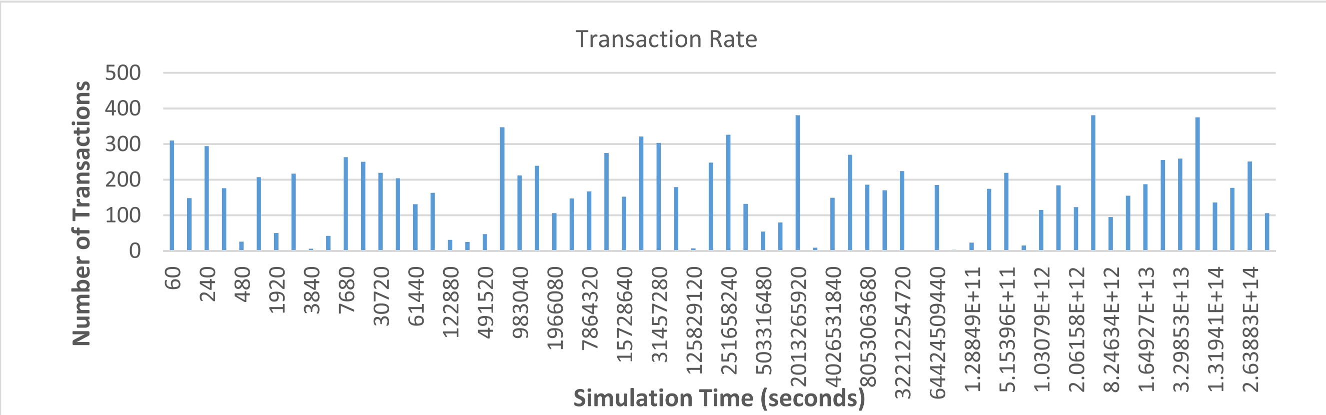

FIGURE 20. The number of transactions executed per block over simulation time.

Algorithm 6 Uncle Block Computations

Goal: To compute the uncle blocks competing for addition in the blockchain

Premises: Let B_i is the i^{th} block competing for addition in blockchain (C_n). B_i can be classified as $B_i^{C_n}$ or $B_i^{U_n}$. $B_i^{C_n}$ is block successfully added to C_n and $B_i^{U_n}$ is the uncle block that is authentic but fails to be added in C_n. Further, N_j is the jth node that want to add B_i in C_n.

```
For each B_i:
    If B_i's N_j does not verify PoG within the specified time then:
        Start broadcasting and ask for B_i details
        Exit
    If B_i's N_j does not verify transactions in B_i within the specified time then:
        Stop broadcasting and ask for B_i details from its N_j
        Exit
    Else
        N_j broadcast B_i to all nodes except N_j
        If all nodes except N_j verify B_i then:
            Consider B_i as B_i^{C_n}
        Else
            Consider B_i as B_i^{U_n}
        End If
    End If
    Count number of B_i^{U_n}
End For
```

---

be identified for improving the number of transactions in Ethereum based blockchain network. Fig. 21 shows the transaction gas limit for the proposed smart healthcare system. A higher gas limit means a large amount of work is required to execute a smart contract and a transaction. The proposed network requires a maximum gas limit of 9500000. This gas number is comparatively lesser than the gas limit set for other transactions [91]. Although the variations in gas limits are uneven but the maximum gas limit is increasing day by day because a large number of users are interested to take part in blockchain activities including the use of blockchain-based applications like games, web browsers, transaction applications, businesses etc. A large number of people would be interested to join the smart healthcare system if developed, integrated and executed properly because it comes under critical infrastructure as well.

Thus, a high quality and quantity solutions are required to handle a large number of transactions in the system. Fig. 22 shows the average hash rate analysis in the proposed smart healthcare system. It is defined as the distributed but integrated computing power required by miners to validate transactions on the Ethereum block. Miner mines a block in such a way that the hash of block should be smaller than the target. Miner charged for mining transactions based on hash rate and they expect that a large amount of processing power should be available in their historical records such that they can fetch more transactions for mining and increase their profits. Miner compares their businesses through their profits and investment in arranging processing power capabilities as well. Algorithm 7 explains the hash rate computation process in detail. Fig. 22 shows that the hash rate varies between 100000 to 200000 GH/s. Miner's rewards, difficulty levels and hash rate are interdependent in the mining business. As the profits in a blockchain network are dependent on transactions and it is increasing day-by-day, more and more miners are taking initiatives to take part in upcoming challenges to block miner business with unique challenges. Fig. 23 ishows the simulated number of patients and operations handled by a doctor daily. Results show that in a day a doctor works in two shifts (morning and evening). In the morning shift, the doctor diagnoses patients and put on medication. Whereas, evening shift is to operate the patient. In results, a minimum and a maximum number of patients handled by a doctor varies from 10 to 15 and the number of operations conducted by a doctor varies from 1 to 5. Every single doctor gives on an average of 10-12 minutes in diagnosis and an hour (approx.) for operations. These experimentation results are concluded

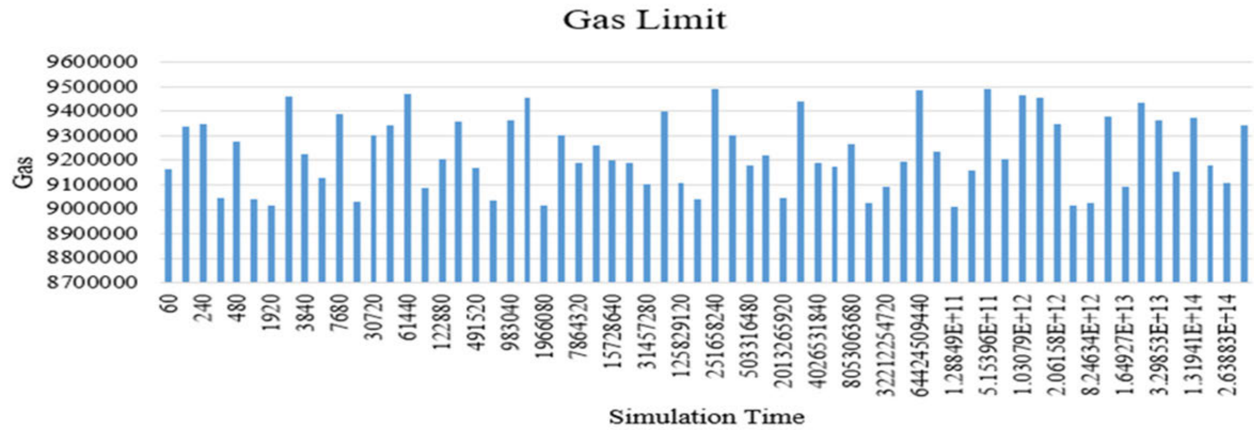

FIGURE 21. Gas limit variations during the simulation for the proposed network.

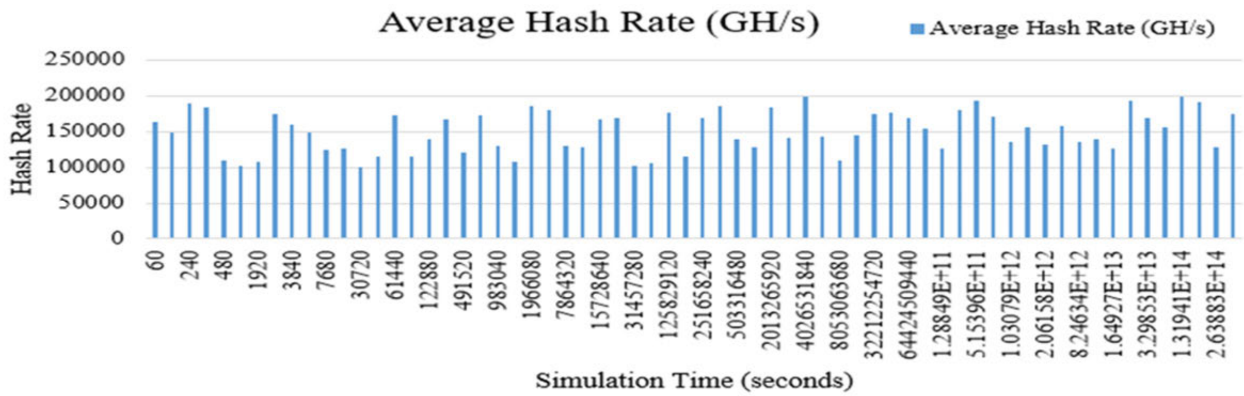

FIGURE 22. Average Hash Rate Analysis in the proposed smart healthcare system.

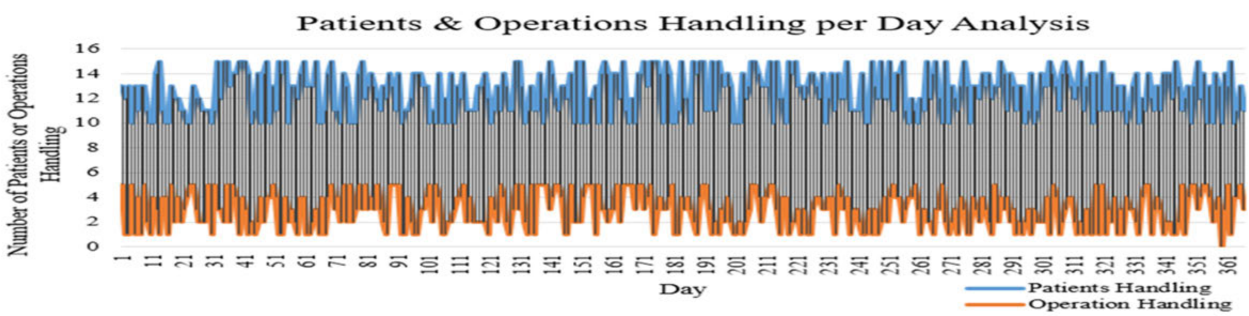

FIGURE 23. Simulated number of patients and operations handling analysis.

from the diabetic patient-based clinical trial case study taken in this work. Fig. 24 shows a comparative analysis of simulation experimentation with Ikeda [92] findings. Comparative results show that the proposed approach will increase the handling of patients because it makes the availability of historical medical data easier compared to the traditional system.

B. SIMULATION USING JSImgraph SIMULATOR WITH QUEUING THEORY

Fig. 25 shows the design of the JSImgraph queuing model for the proposed blockchain approach. In this model, individual blockchains (insurance, doctor, patient, hospital, staff, and supplier) are considered for block creation and transaction execution. All of these individual blockchains are integrated into one in the smart healthcare blockchain network. Each of the individual transaction is associated with a memory pool for competing and consensus building before adding it to the individual blockchain network. Thereafter, a transaction delay is added to compete and build consensus in the main healthcare blockchain network. Here, blockchain integrator collects all individual blockchain network's node requests and add it to memory pool and blockjoiner decide the competing mechanism and consensus-building approach to add a block in the main blockchain network. Fig. 26 shows the

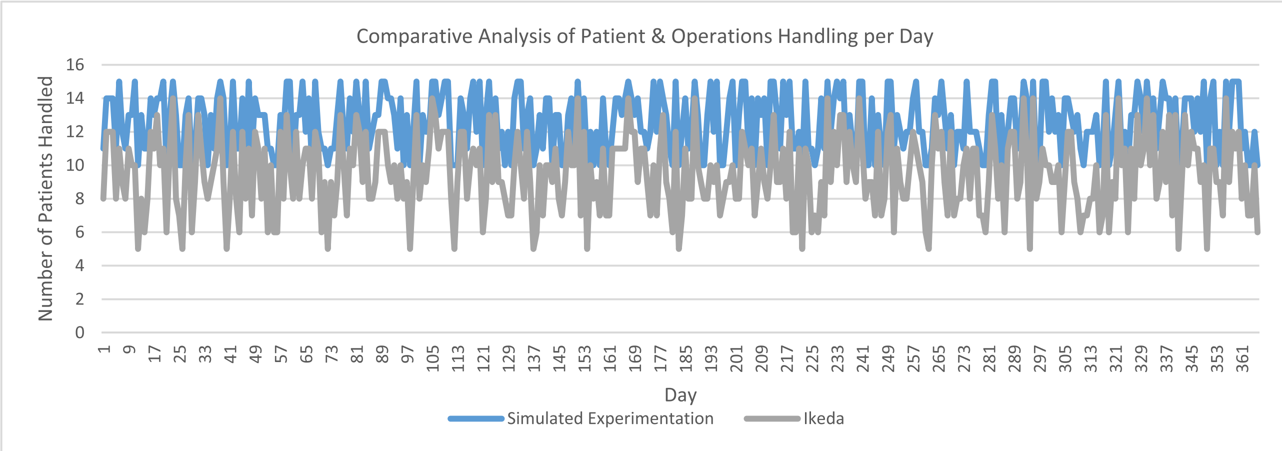

FIGURE 24. Comparative analysis of Patients Handled.

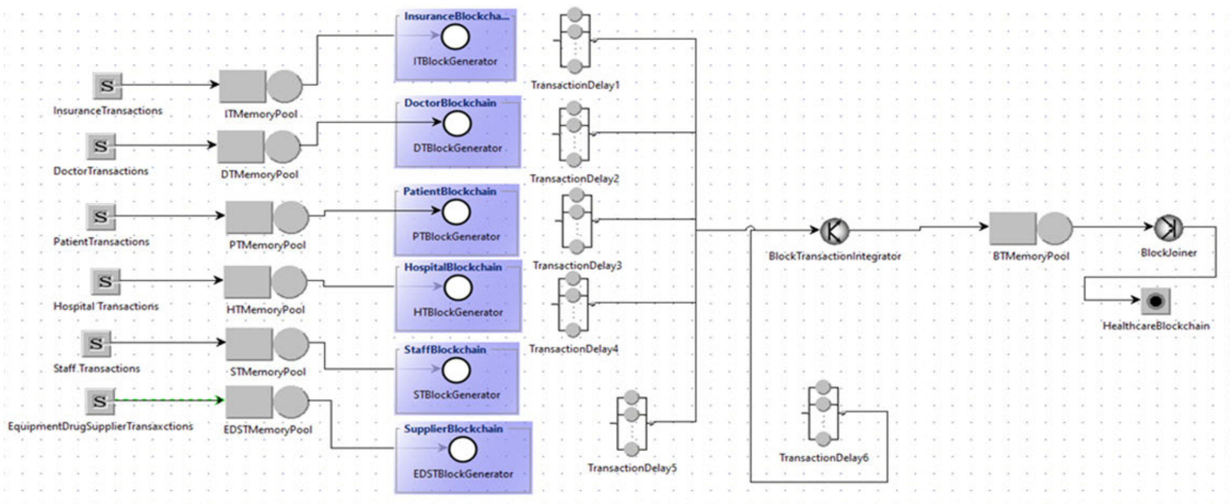

FIGURE 25. JSImgraph simulator model for the proposed smart healthcare system.

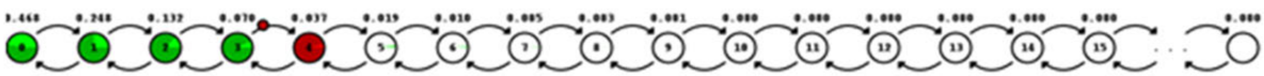

FIGURE 26. Single blockchain representation with Markov Chain M/M/1.

execution of a single blockchain representation using Markov Chain M/M/1. Table 7 shows the simulator parameters used in this model for analyzing the results. In this analysis, input to the system is considered by collecting the real data and program the model to generate similar data. The real data is collected from etherchain.org [91], [93]. Fig. 27 shows the comparative analysis of actual transactions vs simulated transactions generated for analyzing the results. Fig. 27 does not show a clear difference in input data because the error rate difference between actual vs simulated transactions is 0.54 %. Fig. 28 shows the comparative block time variations for six individual blockchain networks. Results show that maximum block time variation is observed in the supplier blockchain network and hospital blocks time variation is at second maximum position. These variations are having large block time because the number of transactions executed in these blockchains are comparatively larger and generate a large amount of data as well. In a supplier blockchain network, a large number of block time values lie below average and this indicates that supplier network is fast and efficient. However, it takes a large block time in certain cases where there may be delays in supplying the special equipment, medicines or unavailability issues to close the transaction. In hospital blockchain, maximum values lie above but close

Algorithm 7 Hash Rate Computation

Goal: To compute the hash rate over different data units and find the average value for given simulation time.

Premises: Let D_i is the i^{th} data unit whose hash needs to be computed, $H_j(D_i)$ represents the j^{th} hash operation over i^{th} data unit, $T_S^{H_j(D_i)}$ and $T_E^{H_j(D_i)}$ is the start and end times respectively when $H_j(D_i)$ operation is executed, $T_t^{H_j(D_i)}$ is the total time when all $H_j(D_i)$ operations over different D_i is observed. Finally, $R_{T_t^{H_j(D_i)}}$ is the average value of hash rate computed over $T_t^{H_j(D_i)}$.

For each D_i:
    Store $T_S^{H_j(D_i)}$
    If $T_S^{H_j(D_i)} \geq T_t^{H_j(D_i)}$ or $T_E^{H_j(D_i)} \geq T_t^{H_j(D_i)}$ **then:**
        Break
    Else
        Compute $H_j(D_i)$
        Store $T_E^{H_j(D_i)}$
        Compute $T_E^{H_j(D_i)} - T_S^{H_j(D_i)}$
        Compute $R_{(T_E^{H_j(D_i)} - T_S^{H_j(D_i)})}$ as the ratio of number of bits in D_i divided by $(T_E^{H_j(D_i)} - T_S^{H_j(D_i)})$
    End If
    Compute $R_{T_t^{H_j(D_i)}} = R_{(T_E^{H_j(D_i)} - T_S^{H_j(D_i)})}$ divided by number of D_i whose hash values are generated.
End For

to the average value. This shows that hospital activities and their transactions are honest, accurate and efficient. A similar trend is observed in insurance cases as well. Although a large number of values are slightly higher in the insurance case as compared to the hospital because it takes time to verify the patient's historical records (if missing). In other blockchain cases (doctor, patient, and staff), block time is much lesser and its variation is close to their average values. Overall, simulation block time results show that the system is efficient in creating block at respective nodes in the blockchain network. Fig. 29 shows the block propagation time variation over simulation time. In this analysis, the complete network's block propagations are considered for evaluation. In the proposed network model, the average block propagation time is 798.82 msec. However, a variation in propagation time lies between 2 msec. to 3.5 sec. The large propagation time is observed in a few cases only. These cases may include heavy transactions, large data, difficulty in solving challenge etc. Smaller propagation time means blocks are transmitted quickly from nodes to the communication channel and received at another end (node). This is an indicator of efficient network services as well. As compared to actual data [91], average block propagation time variation in simulated data is having an error rate of 0.013% that is much lesser. Thus designed, simulated, and analyzed model is close to realities. Fig. 29 shows the comparative analysis

TABLE 7. Simulated parameters used in the model for analyzing the results.

Parameter	Value
Simulator	JSImgraph [90]
Maximum Block Size	1500000
Minimum Block Percentile Utilization	75%
Maximum Block Percentile Utilization	100%
Maximum Number of Uncle Blocks Generated in the System	200
Maximum Number of Transactions per Block	400
Maximum Gas Limit	9500000
Hash Rate	200000GH/s

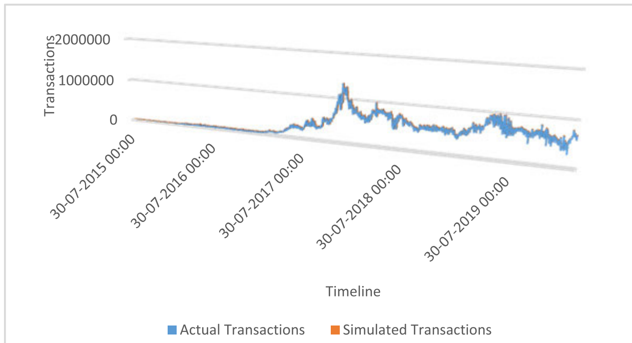

FIGURE 27. Comparative analysis of actual transactions vs simulated transactions generation (with max. diff. of 0.54%).

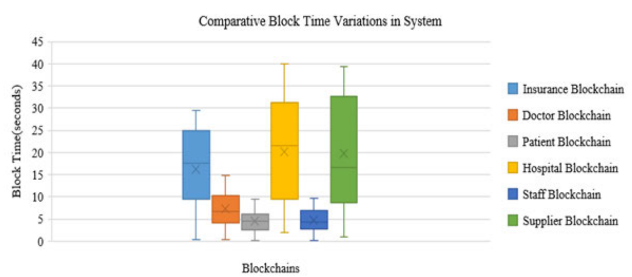

FIGURE 28. Comparative block time variations in the proposed system.

of block propagation time with the S2HS [30] approach as well. Results show that the proposed approach is effective compared to S2HS because of lightweight cryptography primitives and protocols. Further, the PoG approach makes is lighter and secure. S2Hs approach is lighter in the framework but does not specify the use of lightweight cryptography primitives. Further, centralized data analytics for sharing data with end-users increases the overheads as well.

VIII. IMPLEMENTATION

This section explains the implementation of the smart-contract and proposed healthcare system in the Ethereum network and their evaluations.

A. SMART-CONTRACT EVALUATIONS

This section shows the statistics of the 16-smart contract designed, developed and tested for the proposed smart healthcare system. Metric taken for analysis and their evaluations are explained as follows [94]:

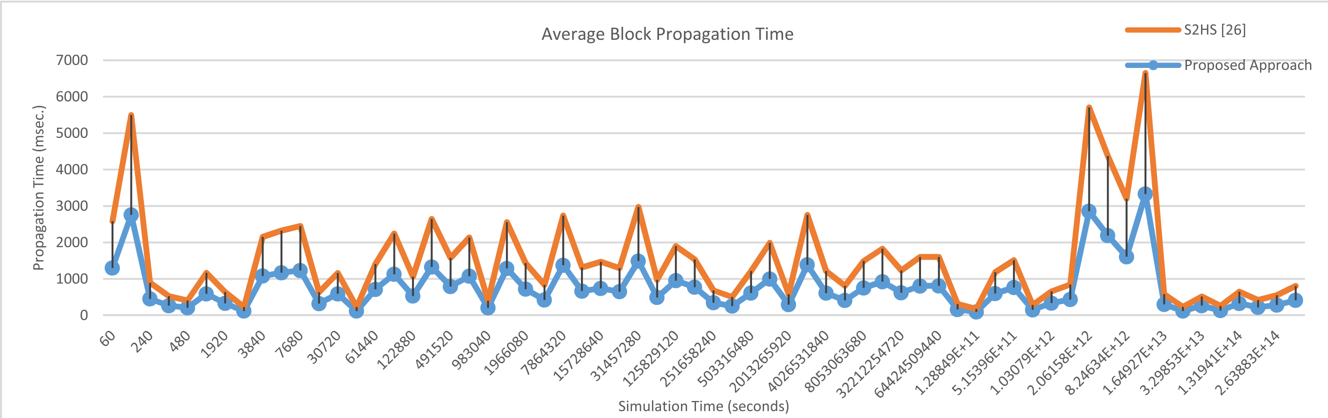

FIGURE 29. Average block propagation time variations where complete networks block propagations are considered for evaluation.

TABLE 8. Designed smart-contract descriptive statistical metric values.

Metric	Minimum	Maximum	Average
SLoC	16	103	51.40
CLoC	1	5	2.12
Nfunc	3	8	5.69
AMCC	1	41	4.21
ANL	0	15.4	0.43
VILV	0	4	2.75
HILV	0	3	0.56
CCV	0	5	2.81
SVV	2	17	8.63
FCV	0	6	1.37

TABLE 9. Implementation parameters.

Parameter	Value
Ethereum Virtual Machine Instances (EVMI)	6
Maximum Blocks in a Blockchain per EVMI	70
System Configuration	Intel(R) Core(TM) i7-8700T, 8.00 GB RAM,1 Gbit/s network connection, 512GB SSD
EVMI Connectivity	Peer to peer
Library to interact with EVMI	Web3.js
Total Smart-contract integrated	16

Source line of code (SLoC) is defined as the number of lines of code written for smart contracts. A count is maintained starting from the first line to the last line in the contract. Table 8 shows that the minimum SLoC value is 16 and the maximum is 103. Commented line of code (CLoC) can be defined as the number of lines of code written in a smart contract that does not execute. These lines are for explanation purposes only. Comments start with "//","/∗", "∗", or it ends with "∗/". Table 8 shows that the minimum CLoC value is 1 and the maximum is 5. Number of functions (Nfunc) is calculated as the number of lines that uses the "function" keyword. Table 8 shows that the maximum value of Nfunc is 3 and the maximum is 8. Average mccabe's cyclomatic complexity (AMCC) is defined as the average value of the "number of branching statements +1" presents in the function [95]. Branching statements include "if","if-else","for","while","do-while". Table 8 shows that the minimum AMCC value is 1 and the maximum is 41. Average nesting level (ANL) is the average value of the nesting level of a control structure within the functions of a contract. The nesting level of an individual function can be calculated by traversing all its source lines of code in the function's sub-tree having function definition in its root and count the number of branching statements during this traversal from the selected SLoC to function definition including traversal of parent nodes. There could be multiple branching statements in a function which results in multiple nesting level value. A maximum nesting value is the maximum values of nesting level and minimum could be zero (i.e. no embedding). Table 8 shows that the minimum ANL value is 0 and the maximum is 15.4. Verticle inheritance level value (VILV) is termed as the maximum level of inheritance in the verticle direction. A minimum VILV could be zero (i.e. no inheritance) and maximum VILV is the maximum value of inheritance level. Table 8 shows that the minimum VILV value is 0 and the maximum is 4. Horizontal inheritance level value (HILV) is defined as the maximum hybrid inheritance value between any two functions. Minimum HILV could be zero (i.e no inheritance) and maximum HILV is the maximum value of any function that inherits attributes hybrid from multiple functions. Table 8 shows that the minimum HILV value is 0 and the maximum is 3. Contract coupling value (CCV) is realized as how many other contracts are used by a particular contract. Minimum CCV value could be zero (i.e. no inheritance or object creation) and the maximum value is the maximum number for a contract that uses other contracts. Table 8 shows that the minimum CCV value is 0 and the maximum is 5. State variables value (SVV) signifies the number of state variables declared in a contract. A minimum value could be zero when no state variable is declared and the maximum value could be the measured number of variables for a contract. Table 8

TABLE 10. Comparative analysis of JSImgraph simulation and implementation.

Blockchains	JSImgraph Statistics		Implementation Statistics		Error Percentages	
	Average Block Time (seconds)	Block Propagation Time (milliseconds)	Average Block Time (seconds)	Block Propagation Time (milliseconds)	Average Block Time (seconds)	Block Propagation Time (milliseconds)
Insurance	16.18	578.42	16.38	578.32	1.22 %	-0.017 %
Doctor	7.25	314.57	7.21	315.37	-0.55 %	0.253 %
Patient	4.52	296.87	4.72	296.87	4.24 %	0%
Hospital	20.25	798.09	20.25	797.89	0 %	-0.025 %
Staff	4.96	301.24	5.06	301.14	1.97 %	-0.033 %
Supplier	19.85	742.49	20.05	742.89	0.99 %	0.054 %

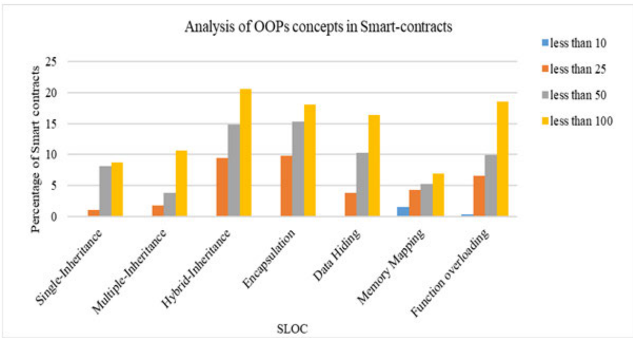

FIGURE 30. Analysis of object-oriented programming concepts in designed smart-contracts.

shows that the minimum SVV value is 2 and the maximum is 17. Function coupling value (FCV) represents the maximum number of functions from other contracts called by a single function. For a contract, it is the maximum value among all of its functions. The minimum value is 0 (i.e. mo other contract's function called) and the maximum is the measured value. Table 8 shows that the minimum FCV value is 0 and the maximum is 6.

Fig. 30 shows the comparative analysis of object-oriented programming concepts used in designing smart-contract in solidity. Various concepts used for analysis include single-inheritance, multiple-inheritance, hybrid-inheritance, encapsulation, data hiding, memory mapping, and function overloading. Among inheritance, a large percentage of smart contracts use hybrid-inheritance. Whereas, multiple-inheritance is preferred over single-inheritance. In comparison to other object-oriented concepts, the hybrid inheritance object-oriented concept is used maximum and the memory mapping concept is minimum. If the percentage of contracts considered is less than 50 then encapsulation is used maximum times after hybrid-inheritance. Whereas, function-overloading is used after hybrid-inheritance if all smart contracts are considered altogether for analysis. Data Hiding is comparatively used higher than single-inheritance, multiple-inheritance or memory mapping for all four scenarios (less than 10, less than 25, less than 50 and less than 100).

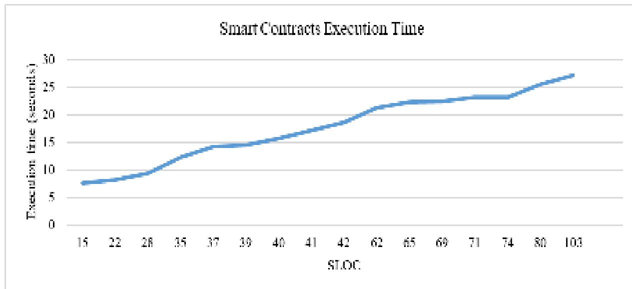

FIGURE 31. 16-Smart contract execution time analysis.

Fig. 31 shows a sixteen smart contract execution time analysis. There are sixteen smart contracts designed in the proposed work. Fig. 31 shows that execution time increases with an increase in the source line of codes. This growth is found to be linear and minimum execution time is 7.5 seconds for a contract having 15 SLoC and maximum execution time is 27.1 seconds for a contract having 103 SLoC.

B. IMPLEMENTATION AND EVALUATION OF THE PROPOSED SMART HEALTHCARE SYSTEM USING ETHEREUM

In implementation, Ethereum virtual machine [96], Metamask (as wallet) [97], Remix (as IDE) [98], Geth (command-line interface) [99], Ganache (account creation) [100] and Athena (web interface) [101] are used to develop a blockchain and analyze the performance. Here, lightweightweight cryptography primitives and protocols are used along with PoG for ensuring the security [87], [88]. Fig. 32 shows the implementation screenshot in which block migration, in blockchain with smart contract execution in ethereum network is shown. Table 9 shows the implementation parameters considered for this small-scale experimentation. Table 10 shows comparative results analysis of simulation and implementation outcomes. Here, individual (insurance, doctor, patient, hospital, staff, supplier) blockchain' average block time and propagation time are compared. Results show that the hospital's average block time and patient's block propagation time are having 0% errors. In other cases, the error percentage varies from −0.55 to

```
1_initial_migration.js
======================

   Replacing 'Migrations'
   ----------------------
   > transaction hash:    0xa1a5677cd29593ba089930754ca5c17e89f5d53ba74f4c800ede181d9e2aca07
   > Blocks: 0            Seconds: 0
   > contract address:    0x5E7990aDc3153A655aa11A7CE235cFA016025A48
   > block number:        49
   > block timestamp:     1588835009
   > account:             0xc58e7d8a77492872634d169d71ced33E38d2e251
   > balance:             99.8171129
   > gas used:            188483
   > gas price:           20 gwei
   > value sent:          0 ETH
   > total cost:          0.00376966 ETH


   > Saving migration to chain.
   > Saving artifacts
   -------------------------------------
   > Total cost:          0.00376966 ETH
```

FIGURE 32. Block migration, blockchain construction and smart contract execution.

4.24 in average block time and −0.033 to 0.253 in block propagation time. Associations among blocks or blockchains and their transactions, change is system configurations or simulator result prediction mechanisms could be the reason in error percentage variations.

IX. CONCLUSION AND FUTURE DIRECTIONS

The advantages of integrating blockchain technology and Industry 4.0 trends are increasingly explored nowadays. The majority of smart healthcare systems either concentrate on data security issues or large data management without understanding the ground truth to make it feasible for end-users. The integration of blockchain technology, Industry 4.0 and healthcare system (named Healthcare 4.0) provides various capabilities including automation, immutability, transparency, security, data tamper protection, distributed and well-managed approach, fault tolerance, quality-of-service, data redundancy, etc. to applications like healthcare. The proposed approach takes advantage of Healthcare 4.0 in protection from the failure of central authorities and applies a decentralized approach, system and data security, performance improvement, easy data maintenance etc. and proposes smart healthcare functionalities in detail. A simulation-optimization approach is proposed to improve the performance of the overall system and sub-systems. The proposed approach is tested, verified and validated through simulation and implementation. Different parameters are taken in simulation and implementation to evaluate the performance of the system and its dependent and independent variables. Implementation and simulation results show an error variation of -0.55 (minimum) to 4.24 (maximum) due to a change in environment and simulator constraints. This comparative analysis validates the proposed approach. In future directions analysis, it can be concluded that a large number of mediums to large businesses in healthcare domains are moving toward Healthcare 4.0 trends-based approach and it is soon reflected to be the revolutionary approach by replacing the present traditional or digital healthcare systems. In future, the proposed work will be extended to be implemented over different blockchain network with different tools and techniques. Further, a comparative analysis of present and future approaches will be drawn.

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