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Blockchain Technology in Healthcare: A Comprehensive Investigation into Medical Data Protection and Emerging Challenges

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Abstract. Due to the rapid advancement of network technologies, blockchain has emerged as a novel area and is capturing global attention. Meanwhile, healthcare institutions are struggling with unprecedented challenges posed by massive volumes of medical data. Therefore, the security mechanisms and immutability features of blockchain are suitable for these problems. In this review, it analyzes the current situation of the medical healthcare system at first and points out the requirement for not only a secure but also an effective management system. Moreover, the article includes specific applications of blockchain system in medical uses. Focusing on the application in protecting and delivering patient information, there are two integrations to combine blockchain with other technologies. One is Chaotic Arnold's cat map, which can either encrypt or send data to a cloud server. Another is Microsoft Azure, which can help to classify lung and colon cancer. Besides, blockchain technology can address the needs of 'data hungry' for AI models, integrating different data sources to help train AI databases. Furthermore, the medical supply chain is the study region as well. The blockchain system can be the central network to conduct drones, which may be the medical supply chain to combat COVID-19. Additionally, it is easier to trace illegal or banned drugs by building Drugledger, which uses a blockchain network. Finally, this article contains future concerns and possible solutions for several integrations above. Including scalability considerations, ethical issues, and Integrating difficulty.

INTRODUCTION

Medical treatment is an indispensable part of modern society, serving as the cornerstone of individual well-being and societal stability. With billions of medical services requirements around the world, the healthcare systems generate a mass of data (e.g. patients' records, diagnostic images and disease information). This issue creates critical challenges in data management, particularly regarding security and privacy. Because of the cyberthreats and hacking escalating, effective protection of medical databases has become vital. For example, Ireland's public healthcare system was intruded by a Conti ransomware attack, compromising 400GB of patient records and staff data [1]. Failures at Australian Clinical Labs culminated in a cyber-attack, which exposed over 200,000 client health records on the dark web [2]. To solve the problems in data vulnerabilities and cyberthreats, blockchain technology emerges as a transformative safeguard. Blockchain is a decentralized network, which can encrypt data and place patients' information at different nodes. In addition, blockchain has characteristics like immutability, consensus, and decentralized space, etc. These features may increase the security levels of medical systems.

The application of the blockchain system in medical healthcare data has several types. A previous study combined cloud environment and blockchain technology, aiming to encrypt the data before storing or sending medical data through public clouds by using a blockchain based Chaotic Arnold's cat map Encryption Scheme (BCAES) [3]. Due to the consensus mechanism and distributed nature of blockchain, it brings a higher security level for preventing eavesdropping and sending medical images and data. Another previous study applied blockchain technology to diagnosing lung and colon cancers, managing medical data as well. The paper combined blockchain and Microsoft Azure cloud services, to increase the accuracy for lung and colon cancer classification and also build secure access for patients to upload CT scans [4]. Besides combining with other technologies, previous research has encrypted

healthcare data in blockchain by using Elliptic Curve Cryptography (ECC) to secure biomedical image processing while maintaining privacy [5]. The blockchain environment enables medical data to be encrypted and transmitted directly using ECC. Not only for increasing the security level, blockchain technology can also be used in managing healthcare records. Moreover, broad connections between doctors, patients, and researchers are made possible by interoperability, which leads to more precise and individualized treatment plans. A medical blockchain network can be formed to connect various medical organizations [6].

Previous studies demonstrated that integrating blockchain with healthcare data establishes a robust security framework, ensuring immutable audit trails and precise transmission. These advancements validate their transformative potential. This paper will summarize the innovative applications and combinations of blockchain implementing in medical healthcare data. The remaining structure of the review will be as follows. First, the paper will include the evaluation and classification for the existing technical project in section 2. Then, in section 3, the essay will discuss the lesson learnt from studies and the challenges or contradictions. Finally, section 4 summarizes the essay, and draws a conclusion. Also, suggesting directions for future research.

METHOD

Preliminaries of Blockchain

Blockchain technology, also known as distributed ledger technology, was first demonstrated in a technical paper published in 2009 by Satoshi Nakamoto [7]. Furthermore, blockchain can be defined as a ledger that preserves immutability while streamlining the process of storing transactions and monitoring properties in network systems. The property or asset can be intangible (such as copyrights or branding) or tangible (such as a house or piece of land). A blockchain network can track anything that is traded, reducing fraud risk and cutting costs for all included [8]. In other words, people can trade on blockchain peer to peer without a third party or central institution. Transactions follow rules that called “smart contracts”, which allows despite traders who avoid relying on any third-party middlemen and also do not completely trust the other party to dominate mutual transactions [8]. More specifically, the term “blockchain” is originated from the method it recorded the transactional data. It connects a sequence of blocks which contain header and transactions as a chain (the structure can be seen in Figure 1). Each header involves previous hash value so that when an attacker manipulates information in a block, it influences all the previous value. Therefore, blockchain is an immutable append-only public ledger.

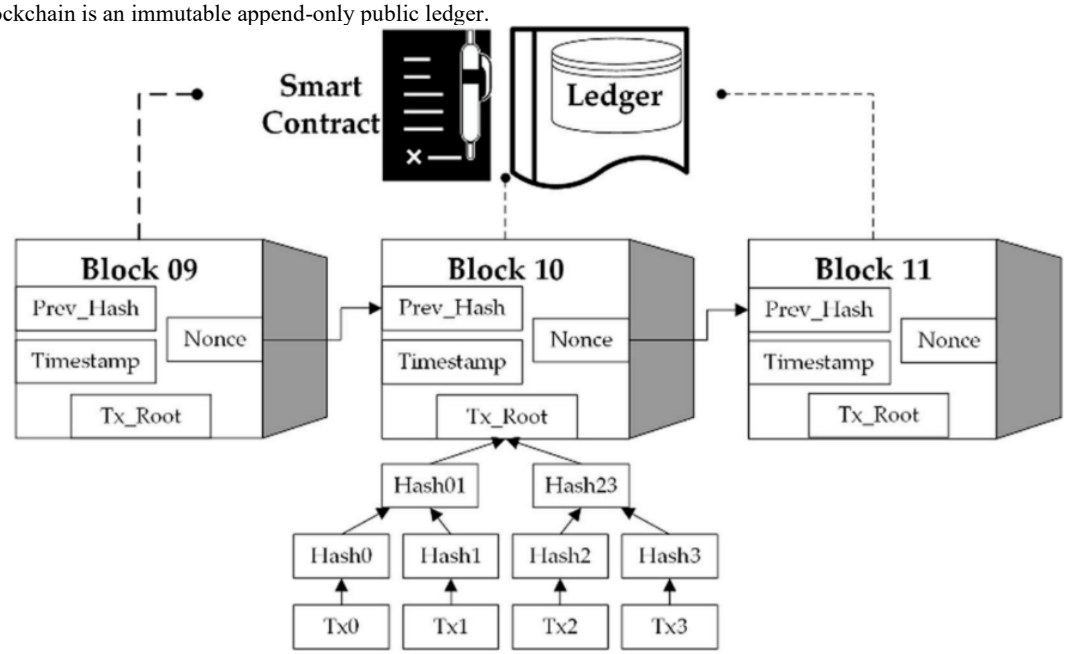

FIGURE 1. The framework of blockchain [8].

Application of Blockchain in Protecting Patient Information

Blockchain and Chaotic Arnold's Cat Map Encryption Scheme

Preserving the medical images and maintaining their reliability are crucial. An assailant is capable of altering medical images. Disease diagnosis will be inaccurate as a result of the data modification or erosion in the image. As a result, a robust and reliable method for securely transmitting sensitive medical information across public channels is needed. Inam et al. proposes to create a blockchain based Chaotic Arnold's cat map Encryption Scheme (BCAES). Arnold's cat map encryption algorithm was initially used by BCAES to encrypt the image. The signed plain image document is then stored on the blockchain after the image has been sent to the cloud server. By using this model, clinicians can verify the legitimacy and data integrity of patients' medical photos once they have been decrypted using a signed document kept on the blockchain [3].

Integrating Blockchain with Classification of Lung and Colon Cancer

Another study for lung and colon cancer classification creating an integration framework of blockchain and Microsoft Azure also preserves patients' data privacy and security. Blockchain technology records private patients' information, including medical picture analysis and storage, in an unchangeable ledger. Patients can upload their scan to Azure Blob Storage. After that, Azure function will preprocess the data. Additionally, only authorized personnel can access medical data under certain situations thanks to the smart contracts included in the blockchain integration, which enable rule-based access control. These preserve the confidentiality and integrity of patient data while ensuring the precision of cancer detection [4].

Application of Blockchain in Treatment

Blockchain Integrate Data to Train AI Model

Krittanawong et al. points out that the requirements of 'data hungry' AI application in medical treatment can be addressed by blockchain database. Convolutional neural networks were recently trained using electrocardiogram (ECGs) from 53,549 patients and provided cardiologist-level diagnostic accuracy for arrhythmias [9]. However, some arrhythmias were not well-represented in that data source, which might influence the integrity of module. While blockchain technology can support the creation of databases that integrate diverse data from various medical devices, healthcare institutions, and non-medical sources. Addressing the scarcity and imbalance of training data for AI applications by sharing data. Besides, blockchain provides capability to trace independent block (record) types and dissect granular data, which means it can easily trace geographical variations from the TOPCAT trial. In this way, blockchain technology enhances AI model adaptability to genetic, geographic, or demographic differences in disease management and treatment outcomes [9].

Application of Blockchain in Medical Supply Chain

Blockchain and Drones

Saeed et al. investigates combating COVID-19 by using drones to transport medicines and goods to a given quarantine area. Therefore, blockchain may become a 'meta controller' to make a data sharing network and enable drones to update information about time, resources, data of states, delivery images, and location. A consensus algorithm in the system can improve partitioning and scalability of drones' network [10].

Blockchain and Drug Traceability System

There is another study carried out by Zakari et al. showing the application of blockchain technology in tracing medicine supply chain. Tracking where the drug has gone and predicting where it will go along the drug supply chain is distinctly important. Therefore, strengthening the security and reliability of the drug traceability system is necessary. A scenario-oriented blockchain system for drug traceability and regulation dubbed Drugledger is the innovation of the

study. The application of blockchain reconstructs designing logic and service architecture by dividing the former service provider into three independent sections and guarantees the privacy and authenticity of traceability data [11].

DISCUSSION

Limitations and Challenges

Although significant progress has been achieved, applying blockchain technology to medical healthcare still faces several limitations and challenges. This article will focus on not only the inherent technical constraints of blockchain but also the challenges of practical integration and points out three key difficulties.

Scalability

The capability of a blockchain network to handle high-volume network traffic while preserving peak network performance is known as scalability [12]. Theoretically, the speed of blockchain transaction processing is low (especially for public blockchain), which can indicate the network scalability. For example, Bitcoin has about 7 transactions per second, and Ethereum about 30 transactions. However, this kind of amount is extremely difficult to support the high frequency data interactions in medical healthcare. Additionally, the real-time monitoring equipment will transmit data continuously for a long period, and image delivery takes massive volume. Unluckily, these hard works are common in medical areas, such as 24-hour blood pressure monitoring and medical image (e.g. CT scans, MRI). Therefore, it may cause network congestion or low processing speed in practical implementation, which may negatively influence patient satisfaction and treatment efficiency. Maintaining security and transparency while guaranteeing blockchain efficacy is an ongoing challenge.

Ethic Problems

It is necessary and important to consider ethical problems, because the issue is closely connected to patient recognition. Even while patient identities are kept confidential, it is not always ideal for medical data stored in a blockchain ledger to be publicly accessible [9]. Essentially, the transparency of blockchain ledgers predestine the exposure of patients' information. Relational institutions can share data, such as medicine labs or cooperative enterprises. However, patients cannot delete the uploaded data because of the immutability of blockchain ledgers. This contradiction is the main issue for how to balance patients' rights and data recording. Another ethical consideration is more specific. In the application of blockchain and drones, inhabitants have to be considered for scanning procedure. Further, drones will fly inside residents' homes to perform. However, the scanned image analysis takes time due to capacity to collect data. This process may violate individual privacy and cause the dispute of rights [10].

Integrating Difficulty

The third challenge is practicality. Actually, the existing healthcare network system is already established and deeply entrenched in the infrastructure of hospitals and laboratories. The widely adopted platform, such as Electronic Health Record (EHR) systems, can be the evidence. Therefore, to integrate blockchain technology into this ecosystem would represent a huge amount of undertaking. It not only requires meticulous attention to system security and integrity but also needs to minimize disruptions to existing medical workflows. To analyze further, even if such an advanced system is successfully developed, it would likely present a steep learning curve for both patients and doctors. Then specialized training or the recruitment of technical support personnel would be essential to ensure effective adoption, which costs a lot either in finance or time.

Future Prospects

Future studies may focus on solving the challenges mentioned above. The review provides several solutions to discuss some possibilities for issues. 1) For scalability limitation, the strategy to divide network nodes into smaller parts to reduce operating burden can be considered. A published study carried out by Matani gives an example which shows a Multi-Level Sharding model to optimize the scalability of blockchain system. Different from previous studies, this paper investigates practical environments, the nodes are heterogeneous and possess a range of computational,

storage, and interaction capabilities. In the model, the nodes are partitioned into smaller subsets. And they greatly increase transaction throughput by processing discrete sets of transactions in parallel [13]. Therefore, future researches can focus on applying hierarchical structure in blockchain to address scalability issues. 2) The ethic problem is more likely to connect with personal privacy. Therefore, future research can focus on implementing hierarchical access mechanisms to guarantee varying levels of data accessibility for different user groups. For example, doctors, clinical researchers, and some medical enterprises could be granted tiered permissions, allowing access only to the specific patients' information which is necessary for their roles. Therefore, the strategy follows the principle of data minimization. The blockchain system can indirectly fulfill the demand for "delete" as well through private key management. When a patient requires data removal, the system could destroy the corresponding private keys, making the encrypted data that stored on the ledger permanently unreadable. The benefit is this method preserves the immutability of blockchain while technically achieving compliance with privacy regulations. 3) To add blockchain network technology to existing medical systems, a reasonable solution is to construct a divided but cooperative system. The idea is that only recording the key hash value in blockchain network, such as patient ID, treatment image, and surgery record. Then, keeping other raw data in existing HER system to avoid a large-scale data migration. Besides, to address the problem of usage threshold, the hospital may set online forum or library to help users familiar with the system.

CONCLUSION

This review has summarized a series of innovative applications and combinations of blockchain technology implementing in medical healthcare systems. More specifically, the study includes applying blockchain in protecting patient information. For instance, combining with Chaotic Arnold's cat map encryption model to ensure data integrity and authenticity of medical images. Also, integrating with classifying lung and colon cancer, this guarantees the precision of cancer detection and the privacy of data. Beyond that, the article contains the application in treatment to train AI model by using blockchain to integrate data sources. Finally, the opportunity of applying blockchain in medical supply chain is involved as well. Using a decentralized system controls drones or tracing drug supply chain. However, this idea still has to face several limitations and challenges. Future studies could follow the guide of the article, investigating further into scalability issues, ethic problem, and Integrating difficulty.

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