Blockchain in the Healthcare Sector

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The emergence of blockchain technology makes it possible to address disparate distributed system security concerns in formerly ridiculous practices. A key factor of this ability is the decentralization of the symmetrically distributed ledgers of blockchain. Such decentralization has replaced several security functionalities of centralized authority with the use of cryptographic systems. That is, public or asymmetric cryptography is the key part of what makes blockchain technology possible. The blockchain experience introduces the chance for the healthcare field to implement these knowhows in their electronic records. This adoption supports retaining and sharing the symmetrical patient records with the appropriate alliance of hospitals and healthcare providers in a secure decentralized system, using asymmetric cryptography like hashing, digitally signed transactions, and public key infrastructure. These include specialized applications for drug tracking, applications for observing patients, or Electronic Health Records (EHR). Therefore, it is essential to notice that the principled awareness of the healthcare professionals is the leading point of the right perception ethics.

Keywords: healthcare ; blockchain ; symmetric ledgers ; asymmetric cryptography ; integrity

1. Introduction

Blockchain applications are used by a variety of industries, including finance, healthcare, manufacturing, and education, to benefit from the distinctive set of properties that this technology possesses. Blockchain technology (BT) provides advantages in credibility, trustworthiness, organization, and transparency [1]. With its special blend of properties, including decentralization, immutability, and transparency, blockchain technology (BT) has a great deal of promise to support a variety of industries [2]. Researchers anticipate that this technology will have positive applications in academia and science.

One sector where blockchain is anticipated to have a big influence is healthcare. Researchers and practitioners in health informatics constantly struggle to keep up with the advancement of this field’s young but quickly expanding body of research. This entry presents a comprehensive assessment of recent studies investigating the use of blockchain technology in the healthcare industry [3].

Healthcare is an important sector for both the developed and upcoming nations [4]. The overall capabilities of the medical and healthcare sector have been improved further by initiating innovative and latest computer technologies within the sector. Such advancements in computer technologies may help physicians and other relevant health providers with the timely diagnosis and management of numerous health-related problems [5]. Different revolutionary and emerging computer technologies have since been applied within other sectors with highly promising outcomes. Such technologies comprise the Internet of Things, Blockchain, Data Mining, Cloud Computing, and the Internet of Things, Blockchain, Data Mining, Cloud Computing, and Internet of Things, Blockchain Data Mining, Cloud Computing, and many others [6].

As Ratta et al. (2021) [7] described, Blockchain is a point-to-point distributed network within which no single third party has been involved in the communication and transaction. Blockchain operates mainly by maintaining a symmetrical copy of the decentralized ledger for all users under the security of asymmetric cryptography. All the undertakings are isolated and not linked to other relevant transactions. For instance, the popular innovatory idea of cryptocurrency is supported by blockchain technology [8]. Similarly, cryptocurrency is highly believed to be very secure and unable to be hacked; the same blockchain concept can be applied in other sectors to enhance security and privacy issues. The healthcare sector is one of the relevant industries where the technology can effectively be applied.

Within the Blockchain, a ledger system that is publicly distributed is accessible to any individual in a symmetrical manner. In this case, the blockchain ledger is the list of records that keep the required information sequentially [9]. The block is the container with all the individual transaction details in this case. The block has both the header and the details of the transaction. The header is responsible for keeping all the information related to the block [10]. With its associated security features, Blockchain can easily be into the healthcare system to enhance the effectiveness of the sector’s operations. The

present entry seeks to establish how Blockchain can be applied in the healthcare sector, highlighting the specific challenges and concerns.

1.1. Blockchain Principles

A Blockchain is a public, decentralized, and distributed database managed by multiple participants, across multiple nodes connected through a peer-to-peer (P2P) network. Blockchain acts as a distributed ledger technology (DLT) where users can digitally verify the issued transactions without the need for trusted third-party (TTP) authority [11]. Typically, Blockchain presents a secure and autonomous consentaneous approach to expanding the DLT over time while keeping the data immutable and irrefutable [12]. The main characteristics of Blockchain-DLT are demonstrated in **Figure 1**.

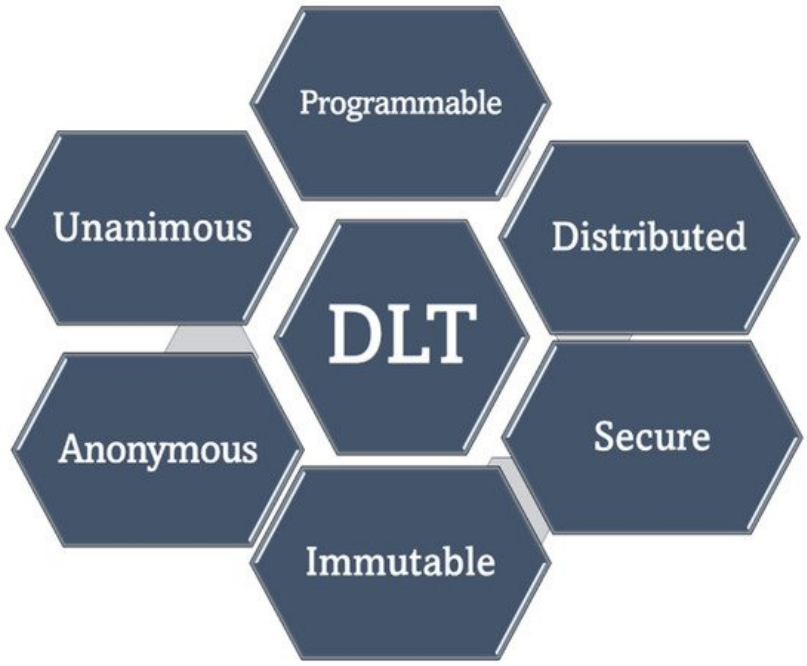

Figure 1. Main properties of distributed ledger technology (DLT) [12].

Blockchain is a sort of DLT that records the transactions using an immutable cryptographic signature called a hash using an algorithm (e.g., SHA 256) [13]. That is, changing one block in the chain is going to be directly noticeable as tampered with. Therefore, for the blockchain system to be corrupted by the hacker, almost, all blocks across the distributed chain need to be changed. **Figure 2** illustrates the principle blockchain anatomy. Every node will have a complete copy of the ledger (blocks) and the block is composed of several data (transactions' list, …etc.). Blocks are connected by connecting every block with its predecessor and subsequent through a hash value. The blocks are linked together chronologically and cannot be modified after they are recorded without writing the entire ledger history again [14]. Nodes use a defined algorithm to reach a consensus on what ledger version is true and accurate [15].

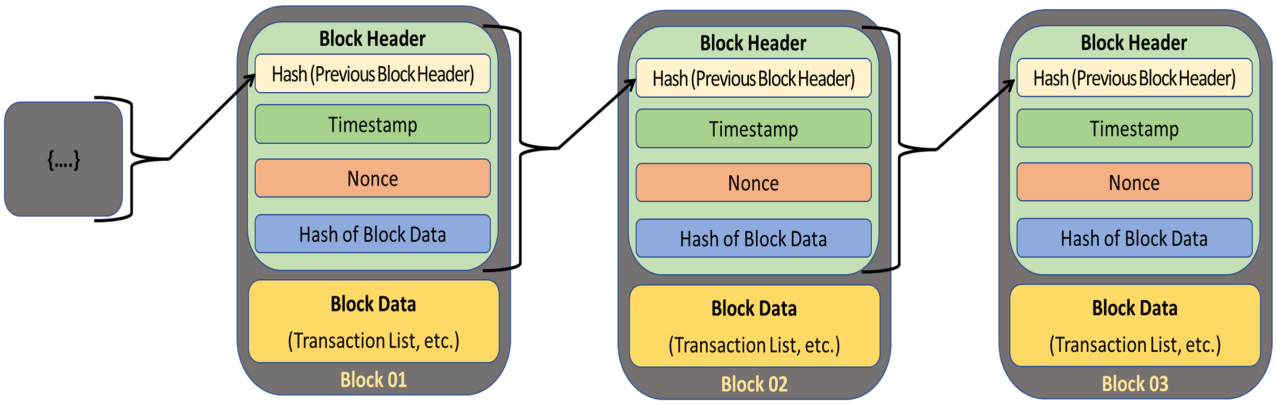

Figure 2. The Principles of a Blockchain Anatomy [15].

Blockchain has a wide range of applications, it provides solutions addressing several security concerns such as industrial applications, financial applications, medical/healthcare applications, smart grid and others [16]. For instance, in healthcare, a blockchain network is useful to preserve and exchange patient data. Blockchain applications can accurately identify

serious and even hazardous errors in the healthcare and medical fields. Blockchain is crucial in processing duplicity in clinical trials for better healthcare outcomes [9].

1.2. Symmetric Decentralized Ledgers of Blockchain

Decentralized ledgers or DL are a set of databases distributed throughout a network and spanning over various topographical sites [17]. A ledger comprises a compilation of transactional accounts that are globally controlled by multiple parties in distinct sites and organizations [18]. The participants can assess distributed ledgers at each network node and obtain a symmetrical (identical) version of the distributed data. Once any changes happened in the ledger (such as editing, adding, deleting, …), then the new changes are repeated and reproduced to all participants in order to maintain the symmetry and accuracy of all records across the decentralized database in a synchronized manner [19]. **Figure 3** illustrates an example of decentralized Ledgers of Blockchain maintaining symmetrical copies of the ledger [20].

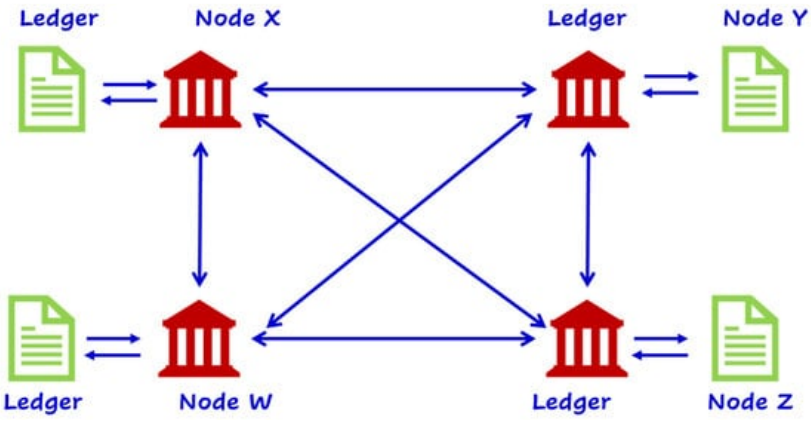

Figure 3. An example of decentralized Ledgers of Blockchain [20].

1.3. Asymmetric Cryptography in the Blockchain

Asymmetric cryptography is effective due to the use of two distinct keys: a public key used mainly for encryption or verifying key and a private key used mainly for decryption or signing key [21]. Asymmetric keys cryptography is perfectly matched for use in blockchain technology to authenticate identities for transactions and personnel.

A major characteristic of blockchain security relies on its pseudonymous where users need not disclose their real identities to establish a new blockchain account, rather, they are identified by means of addresses that depend on asymmetric cryptography [22]. Such asymmetric addresses for digital signatures where the user must sign the transaction digitally with his private key when making a transaction with a blockchain account can be later verified by the corresponding verification key (public key) to verify that the account owner authorizes the transaction. This makes it possible to authenticate transactions without revealing the identity of an account's owner [23].

Also, transactions run the Blockchain since they transmit value/code between different accounts to be performed on a smart contract policy. Each transaction on the Blockchain is digitally signed using an asymmetric digital signature crypto-algorithm. This, in turn, provides transaction authentication and anti-spoofing. **Figure 4** illustrates an example of using asymmetric cryptography in the Blockchain to maintain integrity and confidentiality [24].

Figure 4. An example of using asymmetric cryptography in Blockchain [24].

2. Related Works

Bigini G. et al. (2020) [25] examined the Blockchain's role in Internet of Things (IoT) applications. They summarized surveys and research papers that sought to understand current market conditions and identify obstacles to a user-centric approach to the industry's development. A number of papers have been examined to see how they use Blockchain to move toward a system that is more user centric.

The primary goal of Ratta P et al. (2021) [7] was to use cutting-edge computer technologies like the Internet of Things (IoT) and Blockchain to improve the efficiency of healthcare systems. Ratta P et al. (2021) indicated that IoT and Blockchain technologies can be used in a variety of healthcare applications. It is worth mentioning that Ratta P et al. (2021) indicated that these two technologies have enormous potential in the healthcare industry once they are integrated.

Rahmani MK et al. (2022) [26] highlighted the obstacles of trust issues in a cloud environment and potential use cases of blockchain adoption. The study's findings on the difficulties of cloud computing include the following: centralization, enormous overhead, trust evidence, reduced adaptability, and inaccuracy.

Sharma et al. (2021) [27] offered a detailed literature analysis that addresses the different prospects of applying blockchain technology in healthcare. The review explores the effort done to facilitate the merger of IoT and Blockchain in the medical sector. Sharma et al. (2021) [27] stressed that the Internet of Medical Things paradigm also encourages further research into advanced alternatives to suggest blockchain as a service that provides access to essential consistent blockchain infrastructures for different users or devices. The healthcare applications of blockchain technology are constantly being improved, but there are significant challenges to overcome and important decisions to be made in the future. There is still a need for more testing, experiments, and research before the widespread use of blockchain technology in the healthcare industry can be considered safe. Researchers summarize the related works in **Table 1** below.

Table 1. Summary of related work.

Reference	Description	Advantage	Limitations
Reegu et al. [28]	**Blockchain assists in sharing health-related records among various stakeholders**	**The study addresses the first objective of the application of blockchain technology in healthcare sector.**	**It fails to address the challenges associated with blockchain technology in healthcare sector**
Raatta et al. [7]	**Application of blockchain and internet of things in healthcare and medical sector**	**The study addresses the first objective of the application of blockchain technology in healthcare sector.**	**No mention of challenges associated with blockchain technologies**
Ullah, et al. [29]	**When Internet of Things is integrated with blockchain, then it makes the entire drug traceability system to become more reliable and secure**	**Highlight the importance of blockchain technology in healthcare sector**	**No mention of challenges associated with blockchain technologies**
Siyal, et al. [30]	**Blockchain is applied to develop a kind of atmosphere where two different parties are able to trust one another.**	**There exist numerous ways through which blockchain can be implemented, though the common approach**	**No mention of challenges associated with blockchain technologies**
Makridakis, et al. [31]	**Blockchain system never poses the capability to discover and eliminate the usage of drugs that have not been authorized.**	**It shows security concerns that cannot be addressed by blockchain technology**	**No mention of the wider application of blockchain technology in healthcare industry.**
Abunadi [32]	**Blockchain is applied to develop a kind of atmosphere where two different parties are able to trust one another.**	**Blockchain is more transparent since one change in the transaction process will automatically get reflected for all the relevant users**	**It fails to address the challenges associated with blockchain technology in healthcare sector**
Mehta [33]	**Interoperability within healthcare means exchanging relevant information with each other within the entire blockchain network.**	**Within the healthcare industry, making sure that there is appropriate interoperability among different institutions may be a great challenge**	**No mention of the wider application of blockchain technology in healthcare industry.**

Reference	Description	Advantage	Limitations
Attaran [34]	Lack of trust among the patients and other groups of important stakeholders is also a major issue in the application of blockchain within the healthcare system.	The study addresses the second objective on the challenges of the application of blockchain technology in healthcare sector.	No mention of the wider application of blockchain technology in healthcare industry.
Reegu [35]	Despite the fact that cloud sharing usually makes it easy and convenient to transfer medical images, subsequently improving and streamlining overall patient care, the major stumbling block to the widespread usage is still fear as well as unease regarding the technology	There are a number of issues and concerns regarding the storage and sharing of relevant medical images	No mention of the wider application of blockchain technology in healthcare industry.
This work	It seeks to establish methods for preserving security and privacy while implementing blockchain technology in the healthcare sector. It is important for the designers of the blockchain technologies as well as the common users as it outlines the manners in which the security and privacy of the persons involved can be assured even as the technology continues to gain widespread usage and application in healthcare setups.		

3. Current Issues in the Healthcare Sector and How Blockchain Can Help in Addressing them

The heavy burden associated with healthcare costs as well as concerns regarding increased medical errors instigated a catalyst for general improvement in the overall delivery of healthcare services. Scholars identify the value-based approach to the delivery of healthcare services achievable from the availability and analytics of big amounts of patient data that are collected using health information technology such as blockchain [36]. The recognition of the value of blockchain technology in the improvement of healthcare delivery has prompted players in the sector to contribute many financial incentives to promote the adoption and consequently the implementation of the technology in healthcare facilities [37].

According to Donawa et al. (2019), the use of blockchain in electronic health records provides a health record storage service that therefore facilitates web-based accessibility. The system is frequently designed to give people complete authority over creating, managing, and sharing their electronic health records with friends, family, healthcare professionals, and other relevant data users [38]. As illustrated by Abunadi (2021), the main advantage of such a system is the security and confidentiality associated with it. Scholars acknowledge that the blockchain system is more reliable and secure compared to the paper storage of medical records. It is important to note, however, that there are still a number of issues of concern that are linked to the usage of blockchain in electronic health records. The aim of the current entry is to provide a comprehensive investigation of the challenges and aspects of the application of blockchain in EHRs [36].

Patel, Parthit, et al. (2018) report that blockchain has always been proposed to address the issues attributed to data access and privacy [39]. Fatokun, et al. (2021) explain that it is a blockchain for electronic health records, that is to say, a growing list of blocks that comprise records that are linked through the application of cryptographic hash. There are numerous advantages linked to blockchain in electronic health records. Blockchains can be used to help secure the Internet of Things (IoT) in the healthcare sector. A governance paradigm is used by the blockchain to enforce business logic, which is understood by all participants. A smart contract can therefore be used to govern the necessary access control rules and achieve HIPAA compliance [40]. Additionally, as Keshta, et al. (2021) pointed out, the relevant stakeholder groups have the right to store data in blocks that cannot be edited retrospectively, which means blockchain can be managed by all of these organizations together [41].

4. Application of Blockchain within the Healthcare System

The adoption of blockchain in healthcare supports retaining and sharing symmetrical patient records with the appropriate alliance of hospitals and healthcare providers in a secure decentralized system, using asymmetric cryptography like hashing, digitally signed transactions, and public key infrastructure. There are numerous specific applications which include: traceability of drugs and patient monitoring or rather HER.

4.1. Drug Traceability

Traceability of drugs is always undertaken using a centralized approach within which aspects such as authentication and privacy of data, as well as the system flexibility, are never realized. Several decentralized models have always been proposed to solve issues related to drug traceability [42]. For the privacy and authenticity of traceability data, a blockchain system known as Drugledger has widely been proposed. Drugledger usually integrates the Blockchain with the whole drug supply chain to easily trace such drugs [43]. Drugledger specifically has two different flows of drugs: the information

that flows regarding the drug ledge and the physical flow of the real drug, all of which goes to the drug ledge network in the formula of a chain network of drugs. This new system alters the traditionally understood protocols by grouping the healthcare professionals into various parts: QSP, query service provider; CSP, certificate service provider; and ASP. However, it is important to note that the drug traceability scenario, as illustrated in the present entry, looks so simple theoretically but is overly complex within the real-life case scenario [44].

However, Hamza et al. (2020) [45] highlight that the entire drug traceability system becomes more dependable and secure when the internet of things is integrated with Blockchain. Numerous frameworks have been suggested in the healthcare field regarding drug traceability or patient monitoring systems. The researchers in [7] suggested a structure to help curb drug fraud by tracking every drug within the supply chain system. The greatest aim in this scenario is to help reduce incidences of counterfeit drugs within the Blockchain. The specific and commonest technologies that can be applied to help improve the traceability and visibility of commonest technologies that can be applied to help improve the traceability and visibility of commodities such as drugs are RFID and Blockchain [46].

For a more transparent movement of the drugs, the Gcoin Blockchain model, in which G stands for global control, is suggested; the model equally changes the drug supply chain system from regulating to inspection and surveillance of the drugs [47]. This means a government model that is combined with a decentralized autonomous organization.

Blockchain is applied to develop a kind of atmosphere where two different parties can trust one another. There are numerous ways through which Blockchain can be implemented, though the common approach, as claimed by Siyal et al. (2019) [48], is Gcoin Blockchain. As further argued by the scholar, Gcoin Blockchain can easily track every drug in the same ways Blockchain tracks the movement in bitcoin. It assists in building a superior level of trust and transparency between sellers and buyers [48]. It is important to note further that Gcoin aims to improve overall data efficiency.

In India, for instance, several lives are considered at risk due to the use of fake drugs. A proposed framework of Blockchain can therefore be applied to help detect the possibility of fake drugs within the supply chain. Such suggested frameworks are based on Hyperledger fabric kind of architecture, within which one PC works as the main beneficiary and five different computers are applied when making the orders. The system is fully dependent on blockchain technology [49]. Moreover, the supply chain of drugs from the drug-producing stores to the local intermediaries and clinics or retail drug shops and hospitals is managed by the application of Blockchain, which assists in tracking all the fake drugs.

The system, in this case, was tried in several case scenarios such as audits of drugs in distribution, stolen drugs, or fake distribution of drugs. The blockchain system was compared with other systems in numerous parameters such as resistance against any given point of failure, detection of counterfeit drugs, identification of diverted drugs, spying for drug shortage, security, privacy, transparency, and immutability [4]. However, Makridakis et al. (2019) [50] outline that the blockchain system never poses the capability of discovering and eliminating the usage of drugs that have not been authorized.

Regarding medicine, the commonest threat is that the manufactured medicine is never received by the pharmacy and can easily get replaced with a counterfeit supply chain. As emphasized by [51], the supply chain approach can never trace drugs that have landed in the wrong hands. For instance, India produced the majority of counterfeit medicines in 2017 and presently it is approximated that close to 35% of counterfeit medicine was sold across distinct parts of the globe. To come out of these problems, Abunadi (2021) [36] proposed the usage of Blockchain and claimed that it is more transparent since one change in the transaction process will automatically get reflected to all the relevant users. With its decentralization concept, Blockchain can analyze the results on two platforms: Hyperledger and Ethereum. Within the Ethereum Blockchain, every operation needs some fees. Miner is provided money to perform transactions and maintain the Ethereum network [52]. There has never been a major need to know your Customer (KYC) within such a process, resulting in some sort of blind spot, which shows researchers the individual who might be using the account. Blockchain applying Hyperledger, on the other hand, never needs fees, making it easy for the individual producer to undertake the transaction.

4.2. Electronic Health Record

An electronic record includes the necessary vital administrative and clinical data of the patient like demographics, diagnosed clinical problems, medication, and laboratory data, among other reports. Using paper as a means of recording patient data has proved to be very extensive and non-reliable as the world has since gone digital [51]. As a result, most healthcare organizations have resorted to using electronic records to keep their data. Blockchain, a decentralized type of database whose data block is specifically linked chronologically, has widely been applied to enhance HER performance. Arunkumar (2020) points out that numerous parties within the healthcare industry need to manage the personal HER blockchain collaboratively, like the medical specialists, insurance departments, and the hospital. Since the traditionally

known EHR system is trademarked with decentralized design, only one unit of supplier controls the code base, database, and system outputs [53]. It has become difficult for the centralized systems to have full confidence from the hospital management, doctors, and patients [36]. Therefore, Blockchain has been considered the solution to the trust issue associated with a centralized electronic health record system. With blockchain technology, all the patient information is stored in the Blockchain through the use of meta mas, and the details of each patient are stored in the Blockchain as independent data blocks. Each block comprises encrypted data. The system record health-related information of an individual patient so that respective health care providers and the patients can easily consult it themselves. In most cases, the data are usually encrypted by a specified algorithm to encrypt all the patient data into a single line bit that is subsequently stored in the block [54].

As Donawa et al. (2019) [38] noted, using Blockchain in electronic health records offers a convenient and symmetric health record storage service that promotes easy accessibility of such records through the web. The system is often designed to allow the patients full control of generating, managing, and consequently sharing their electronic health records with friends, family, healthcare providers, and other relevant data consumers. Abunadi (2021) [36] illustrates that such a system's main advantage is security and confidentiality. Scholars acknowledge that a blockchain system is more reliable and secure than paper storage of medical records. However, it is important to note that several issues of concern are still linked to using Blockchain in electronic health records. The present entry presents a thorough examination of the aspects and issues concerning the use of blockchains in EHRs. For example, Alla et al. (2018) [55] indicated that the patient could lose control across the prevailing EHRs in the course of live actions, despite the fact that the service provider constantly retains the principal stewardship.

Cunningham et al. (2018) [32] report that Blockchain has always been proposed to address the issues attributed to data access and privacy. Fatokun et al. (2021) [35] explain that it is a blockchain for electronic health records, which is to say, a growing list of blocks comprising records linked through the application of cryptographic hash as an asymmetric crypto-algorithm. There are numerous advantages linked to Blockchain in electronic health records. For instance, a Blockchain is a linked peer-to-peer database in which data integrity, availability, and response time are fully guaranteed. Blockchains can adequately facilitate internet of things security in electronic health.

Moreover, the Blockchain works within the governance model, which helps enforce business logic that all the participants accept. It is, therefore, very possible to exploit a smart contract or chain code to control the relevant control policy on access and achieve HIPAA compliance. Keshta et al. (2021) [56] also highlighted that Blockchain is additionally managed collectively by the relevant stakeholders, some of whom. Some have the right to record data in the block that cannot alter retroactively.

Mehta et al. (2020) [31] noted that Blockchain in the electronic health record is symmetrically distributed and append access rights to only its ledger shared among the specified users. Fine-grained access to the ledger is equally implemented to realize an appropriate balance between availability and privacy. **Figure 5** below illustrates the possible access rights of users as applied in the BlockHealthChain. The rights, in this case, include read permission, write permission, read permission with anonymized EHRs, and authorization permission.

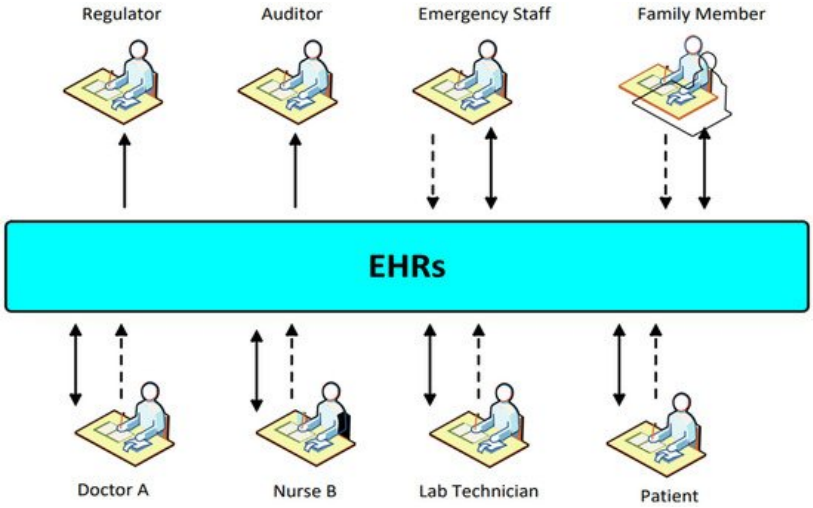

Figure 5. Possible access rights of users as applied in the BlockHealthChain.

It is clear from the figure that within blockchain protocol, different users tend to have different access qualifications for EHRs. With this arrangement, patients have the right to control access to electronic health records, including individual

patient-reported information. The former comprises numerous contents like allergies, demographic information, and numerous contents allergies, demographic information, and monitoring data collected from the applied instruments [42]. The latter, in this case, refers to the updated medical record by the staff of doctors. The patient can authorize family members or health care providers to read and write their personal health information, minimizing the potential risks of tracking and replicating healthcare data.

Nurses, doctors, emergency staff, and laboratory technicians control and manage access to the electronic health record that is updated by themselves. Additionally, they effectively use or disclose protected health information for the diagnosis, treatment, and payment without seeking authorization from the patient [22]. This means having the authorization to grant read or write permission to other relevant entities, in which case the electronic health records are shared within the healthcare organizations.

Attaran (2020) [30] additionally indicated that several classes of users submit various EHRs containing test results, encounter comments, and demographic. For instance, the test result includes several fields: Patient ID, patient name, technician ID, type, indicator, and final result. Each electronic health record in the Blockchain corresponds to a transaction, which must be executed accurately and included within the ledge. All the electronic health records pose lifecycle as shown in **Figure 6** below.

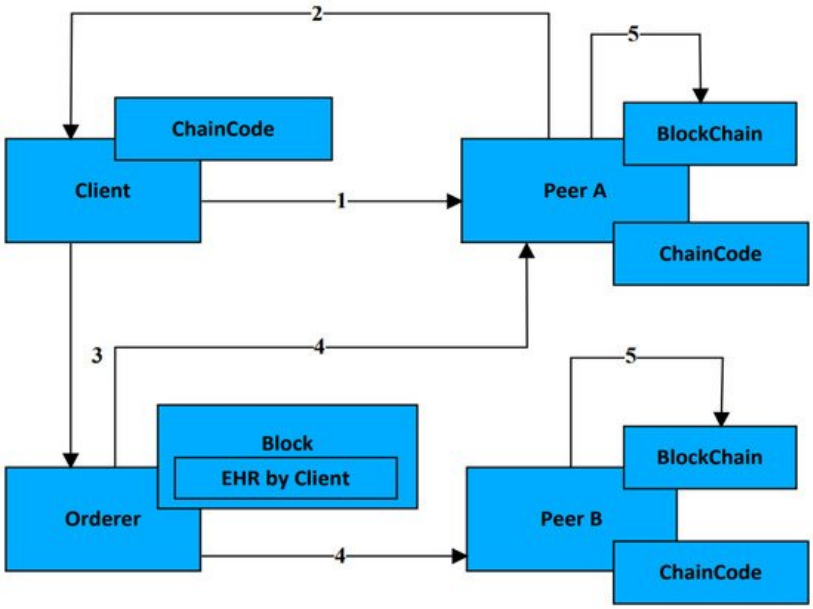

Figure 6. Illustrates the electronic health records lifecycle.

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