ELECTRONIC HEALTH RECORD USING BLOCKCHAIN AND OFF CHAIN STORAGE: A SYSTEMATIC REVIEW

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Abstract—The Blockchain was introduced by Bitcoin [1] for maintaining financial transaction; many researches are going on, to extend the use of blockchain technology in non-financial application. Healthcare domain is a promising industry in which blockchain can have important influence. This paper focus on a systematic review about existing and ongoing research in the field of storing electronic health record (EHR) using blockchain technology. This paper also presents use of blockchain framework in healthcare domain, its challenges and further research.

Index Terms—electronics health record, Blockchain, on chain storage, off chain storage

1. INTRODUCTION

Healthcare is a data-sensitive domain where a large amount of data is produced, disseminated, deposited, and gets retrieved daily. For example, whenever a patient visits hospital, some data will get created which may be used by multiple doctors i.e. physicians/ surgeons etc. within same hospital or hospitals within networks. [3]

Healthcare data contain individual and sensitive information that may attract to cyber criminals. Hence ensuring the security of the electronic health record (EHR) is crucial and challenging due to the exchange of information between the multiple stockholders like doctors, insurance company etc. Furthermore, the confidentiality and reliability of healthcare data must be protected from external attackers and also from illegal access attempts from inside the network or ecosystem. [3]

Therefore, to protect the data from the misuse and also to maintain a definite trust between the different stakeholders like doctor, Patient, Insurance companies etc. A system is needed where the transactions, complete access and storage management was taken over by the technology and blockchain technology can be used for the same.

2. BLOCKCHAIN TECHNOLOGY

Blockchain is decentralized and distributed ledger technology. The blockchain is nothing but chain of blocks, where every block represents a set of transactions. Every Record is referred as ledger and data exchange refers as transaction. A Blockchain makes the use of distributed system to validate each transaction. Very important property of blockchain is that it is a immutable technology i.e whenever any transaction or blocks get added in blockchain it remain unaltered and cant not edit . In addition to this following are few features of blockchain technology

Decentralized: Every node has one copy of data; hence failure of one node does not affect the organization.

Secure: All the data is hashed with cryptography i.e. using key and hence it is secured

Irreversible: Once transaction is stored in Blockchain, it cannot be rollback

Reliable: As Blockchain is decentralized, even if a single node gets fail, it does not affect the entire system, thus makes Blockchain network reliable

Efficiency: As transactions are not controlled by any central authority, it takes less processing time

Like any other technology, Blockchain is evolved from Blockchain 1.0 to 3.0. Bitcoin implemented cryptocurrency which is used for financial transaction is always referred as Blockchain 1.0. Blockchain 2.0 introduced concept of Smart contracts and smart properties. Smart Properties means digital assets, ownership of these smart properties can be controlled by a blockchain-based platform. The smart contracts are the software programs which decide the rules to controlled and managed smart properties. Ethereum, QTUM , Ethereum Classic are some examples of Blockchain 2.0. Solidity is popular language to write smart contracts. Blockchain 3.0 is the third generation of blockchain technology All the non-financial applications blockchain are implemented using Blockchain 3.0 Application such as supply chain management, Electronics health records, Document verification fall under this category [4]. Step by step working of blockchain technology is shown in figure 1.
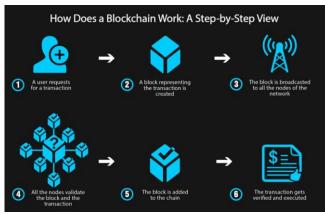
Figure 1: Working of Blockchain Technology [58]

3. BLOCKCHAIN IN HEALTHCARE

To get a clear idea and to identify the scope about storing personalized or electronic health record using blockchain technology, the systematic literature review has been performed. Almost 60 Papers from IEEE, Science Direct, PUBMED, various medical Journals databases are reviewed. Few papers were related to introduction of blockchain technology, IPFS, Etherium and Heperledger. Some papers were survey papers and in some papers a system to store electronic health record was either proposed or implemented. Only those papers which has either proposed or implemented a system are used in this review for analysis. Basic terminology on basis of which analysis of these literature have done are

1. Blockchain Platform and Consensus mechanism Used
2. Scalability or storage Schemes
3. Data Provenance
4. Access Control Methods

This paper also focuses on Opportunities and challenges of using blockchain in healthcare domain.

3.1 Blockchain Platform and Consensus mechanism Used

Etherium[11]and hyperledger[55] are the two major types of blockchain platforms which are used to build non-financial applications using blockchain .Very few papers showed use of bitcoin platform . Fig.1 shows File structure and architecture of Etherium and Hyperledger blockchain. Etherium, Bitcoin are public blockchain platform whereas Hyperledger is framework to build private or consortium blockchain. Blockchain architecture of Etherium and hyperledger is shown in Figure 2.

MedRec is model proposed in [42] uses Etherium client and it requires miners in blockchain, which may lead to a new problem i.e. shortage of Human Resource Quality [22]. In this model whenever patient wishes to share

information they have to spend ether. Therefore Selection of blockchain platform is very important while using blockchain technology in non-financial applications
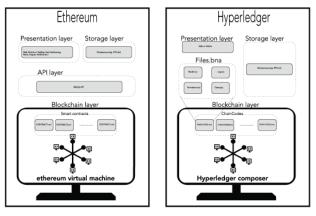

Figure 2: Etherium and Heperledger blockchain architecture and file structure [8]

Blockchain can also be classified on basis of consensus mechanism used by network. Consensus algorithm is the mechanism to check valid transactions and blocks. Only valid transactions or blocks are added in blockchain. Process of consensus is also called as mining and nodes who take parts in mining process are called as miners. Consensus algorithms are primarily classified into two groups, first is Proof Based algorithms and second is Vote Based algorithms [8]. Proof of work (PoW), Proof of stack (PoS) are popular proof based algorithms and Practical Byzantine Fault Tolerance (PBFT) is very popular vote based consensus algorithm. Table 1 [57] shows the comparatives study of PoW, PoS and PBFT.

System Proposed by Hao Guo [36] uses concept of Hyperledger Composer Fabric [20] which is a blockchain implementation platform and supports plug and play consensus mechanism.

Property	PoW	PoS	PBFT
Node Management	Open	Open	Permissioned
Energy Consumption	High	Medium	Low
Tolerated Power of Adversary	< 25 % Computing	< 51 % Stake	< 33.3 faulty Replicas
Example	Bitcoin [1]	Peercoin	Hyperledger Fabric [55]

Table 1: Consensus Mechanism Comparison [57]

3.2 Scalability and Storage Scheme

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Property of a system which handles growing amount of work by addition of resources to the system is known as scalability. One of the major challenge in Blockchain is Scalability. As blockchain is platform created for financial transaction (cryptocurrency) by bitcoin, size of transaction is very small. It is very ineffective to store large files on blockchain as it slow down block processing speeds and leads to the problem of scalability. Abstract data types like MRI, X-Ray images etc cannot directly store in blockchain. This type of data would require links to a separate location. By considering technical and confidentiality constraints data should be stored in ON-chain and OFF-chain formats. [54].Many papers have tried to solve this issue of scalability have solved using different Off-Chain storage.

In most of proposed system a centralized storage like cloud, SQLite and central server is used to store patients data as off-chain storage which again has a chance of single point failure .To avoid this a concept of IPFS is used in many papers like [13][15]. IPFS is inter planetary file system. It is a peer-to-peer (P2P) distributed storage system in which huge volumes of records can get easily stored. For every file, IPFS generates a unique hash and store that hash in a table called as Distributed Hash Table (DHT) and removes duplicate files using version-control history [23].

IPFS generates a unique hash for every file and uses content based addressing instead of location based addressing for file retrieval .It has many features such as high throughput , Security due to mapping of transaction with hash and concurrent access to transaction by peers in network.[15]

3.3. Data Provenance

Data Provenance in a system provides a detailed picture of how the data was collected, where this data gets stored and how it is being used. In other words, data provenance is nothing but "showing your work" in a database. This historical record of information can then be reliable source for data validation and audit purposes. The historical records of data and their origins are always referred as Data Provenance [26].

Most of the paper reviewed, proposed systems have properly shown data provenance. In various proposed system's data is either collected using wearable device or sensors inserted in human body or manually from information provided by patients.

Table 2 shows Off-chain Storage, consensus mechanism, Data Provenance used by various proposed system.

3.4 Access control

Access Control means systems perform identification, authentication and authorization of users and entities by evaluating required login credentials. Using blockchain technology two types of access control can occur

1. **Role based access control**
2. **Attribute Based**

In terms of Electronic health record, the term access control refers to which user will have access to individual / Patient data. Most of the proposed system is patient centric where patients have full access to his own data. Smart contracts have played very important role to specify access in various system.[13] [36] are role based access control where third party would not be able to access a particular data as it is unauthorized user for that particular data .

Ref. NO	Off-chain Storage used	Consensus Mechanism used	Data Provenance
[5]	Cloud	POS	YES
[42]	SQLite	POW	YES
[7]	Central Server	PBFT	YES
[12]	Fast Healthcare Interoperability Resources (FHIR)	Multichain Algorithms	YES
[13]	Inter Planetary File System [IPFS]	POW	YES
[15]	Inter Planetary File System [IPFS]	POW	YES
[36]	Edge Node	---	YES

Table 2: Analysis of various proposed system

4. CHALLENGES OF BLOCKCHAIN ADAPTATION IN HEALTHCARE:

Though blockchain in healthcare has attracted many attention, there are various challenges that needs to be improved while accepting blockchain adoption

1.Public Vs Private Vs Consortium Blockchain –

Blockchain technology can be categories into 3 categories

Public Blockchain: In public Blockchain, all records can be viewed by the public and everyone could read, write and participate in Blockchain consensus process. It is also known as permission less Blockchain In public Blockchain, no one has control over the network , also once data get validated it cannot changed.

Private Blockchain: It is also called as permissioned block chain. It is specific for an organization

and only nodes from those organization are allowed to read , write and participate in consensus process. It is like centralized network which is completely managed by one organization.

Consortium Blockchain: It is specific for group of organizations and nodes from those organizations are allowed to read, write and participate in consensus process.

Though Public Blockchain like bitcoin implementation provides best data integrity due to multiple copies and redundancy of the ledger.

Main Challenge in public Blockchain is Security that means data must be protected and should not open in public domain. Private Blockchain overcome this challenge and hence are popular than public blockchain.

However implementations of private blockchain navigate the blockchain development away from a decentralized to centralized system and the original moto of Blockchain was to avoid centralized systems.[6].

Most of proposed systems have suggested using Private Blockchain/ consortium blockchain like Etherium or Hyperledger to get more security and confidentiality. [25][36] have used hyperledger Fabric where [13] is using Etherium in their proposed prototype. Table 3 [57] shows comparison of private, public and consortium blockchain

Property	Public Blockchain	Consortium Blockchain	Private Blockchain
Consensus Determination	All Miners	Selected set of nodes	One organization
Read Permission	public	Public or restricted	Public or restricted
Immutability	Nearly impossible	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centrality	No	Partial	Yes
Consensus Process	Permission less	Permissioned	Permissioned

Table 3: Different types of Blockchain Overview [57]

2. **Interoperability:** Interoperability is another challenge in field of Blockchain. Interoperability of healthcare records is the degree to which the clinical data can be conveyed across institutional boundaries. Due to the complexities of data in the healthcare domain, this is inherently difficult to achieve interoperability [12]

Interoperability is ability of various related systems, devices or applications to connect in a coordinated manner within and across organizational boundaries to exchange, access and cooperatively use data among stakeholders with aim of optimizing health of individuals and populations [26]

Interoperability can be improved using blockchain technology by exchanging data across multiple systems and can be accessed simultaneously. Improved Interoperability may lead to improved health outcome [37]

In Healthcare domain, data can be shared within institutional boundaries or across institutional boundaries. Most of the proposed systems share the data within institutional boundaries or patient's/ User centric where patients have full right to give access of his own data.

3. **Legal Issue:** Third important challenge is legal issues . The legal issues are related to the law that been implement in IT in order to protect the personal data but by the aggressive protection that cause the difficult to the users to access the PHRs.[2]

Many proposed system have not talk on this topic. But through proper agreement this problem can be solved

5. APPLICATIONS OF BLOCKCHAIN IN HEATH ECOSYSTEM

According to [14], Blockchain technology can not only be used to store Electronic health record but also can be used in various domains like Detection of Medical Fraud, Neuroscience and Clinical Research, Pharmaceutical Industries etc. Various Applications wher blockchain can be used are shown in figure 3.

Where and Why Blockchain can be used in Healthcare?

Clinical Research: as blockchain can be used as decentralized framework, group of researcher can used it for secured data sharing.

Fraud Detection: As transactions in blockchain are immutable, No one can update or duplicate transaction and therefore frauds can get identified easily

Pharmaceutical Industries: For **supply chains** where participants are not known or trusted, **blockchain** technology can add trust, transparency, and traceability.
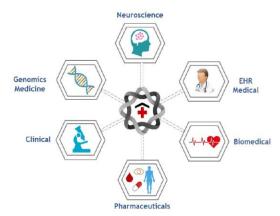
Figure 3: Application of blockchain in Healthcare [14]

6. CONCLUSION

Blockchain signifies a new form of technology which can be used in healthcare domain. There is scope to explore utilization of blockchain in healthcare domain such as the incorporation of hospitals, healthcare start-up, Personal health insurance etc. .Government can also use it to provide various heath schemes.

During literature review it is observed that the current literature is lacking in the above stated application context and statistical comparisons with traditional systems or other proposed systems have not been made anywhere. In future, research agenda should be extended to concentrate on the mentioned challenges.

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