Blockchain-base Healthcare Applications: A Survey

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***Abstract*—After successful research into the use of blockchain technology outside of financial matters, healthcare researchers have gained wide interest in using this technology for security purposes. Although research in this area is fairly recent, it is growing rapidly which leads to the introduction of many survey studies that deal with this context. However, more investigation is required in order to help and motivate researchers to propose new work in this field. In this study, the Blockchain-based healthcare is explored in detail, based on its models and architecture. They can be classified into two main aspects models of healthcare research that rely on blockchain technology, which include the Electronic Health Record (EHR) and Remote Patient Monitoring (RPM)) systems. This study aims to present a brief, critical report concerning systems and applications used to leverage blockchain technology with these two platforms. Furthermore, it provides a comprehensive comparison of these systems and techniques used in a concise manner. It then highlights the benefit of developing blockchain-based healthcare applications and its limitations, and underlines the necessary requirements for better improvement as well as the fields for future research.**

Keywords— Healthcare Systems, Blockchain Technology, Literature Review.

I. INTRODUCTION

In an effort to create advanced healthcare systems, researchers attempt to apply the latest technologies to develop the health care sector and meet its requirements, such as artificial intelligence, electronic health record, remote patient monitoring system, robotics, or nanotechnology. Therefore, it is important to know the latest developments to enable individuals of controlling technology instead of vice versa. Future healthcare concepts are mainly determined by technological factors, which is why healthcare workers must embrace emerging healthcare technologies so as to remain relevant throughout the years that follow [1][2].

Although integrating modern technology with healthcare has many benefits, it may also contain risks. For example, developing the creation of an electronic health care record has many benefits represented by the possibility of rapid access to data and the insurance that it will not be lost. It also reduces costs, since all examinations will be available to doctors. However, storing information electronically makes it vulnerable to hacking and manipulation. The same is applicable to the use of remote patient monitoring technology, although it enables doctors to monitor their patients even if they are in their homes, the risks of data transmission and ensuring that it is not penetrated constitutes a problem for users of this system [3][4].

Therefore, a need emerged to search for innovative technology to deal with healthcare data. Consequently, most of the recent research focuses on using the newest technologies such as artificial intelligence [5], virtual reality in healthcare [6], chatbots in healthcare [7], aadvanced social media [8], ppersonalized mobile applications [9], and blockchain technology to protect healthcare data [10].

Blockchain applications within the health sector improves the general security of patients' electronic medical records, protects data from Internet devices, and objects related to the remote patient monitoring system. As stated in a report presented by the IDC, one out of five medical/health-related organizations intend to use blockchain in managing important information and identity by the year 2020. IT is expected that by 2025, more than half of the healthcare applications (55%) will have adopted blockchain for commercial purposes. By the same year, the healthcare blockchain value will jump to $5.61 billion from the current $170 million [11].

Although many good review papers already exist for research on Blockchain-based healthcare applications, as found in [2][12][13][14], due to the extensive coverage they handle in this domain and related research efforts either incompletely. In this survey, the main focus will be on research that relies on the use of blockchain technology in two basic health care systems, namely the electronic health record and the remote patient monitoring system, as these two systems are believed to be the core of electronic health care that uses Blockchain technology. Therefore, no researches on secondary studies on using blockchain in the health sector will be addressed. For this purpose, the study is built according to:

i. Describing the implementation related to blockchain-based healthcare systems or applications;
ii. Describing the advantages, as well as security and performance limitations of each application; and
iii. Listing a set of research challenges related to using healthcare systems according to the blockchain technology.

On this basis, the present study organized in the following way: Section 2 explains blockchain technology. Section 3 introduces the benefits of using this technology in Healthcare applications. The blockchain-based healthcare applications are classified in Section 4. Section 5 highlights the main challenges of healthcare applications according to

the Blockchain technology. Finally, the conclusion of this study are presented in Section 6.

II. BLOCKCHAIN TECHNOLOGY

Briefly, blockchain technology is a decentralized distributed ledger that first appeared as part of the Bitcoin infrastructure in 2008. Thus, this technology is a major innovation for information technology, as the inherited features of the technology improve confidence by means of transparency and traceability in any transaction of data, commodities and financial resources [15].

Blockchain technology works according to three important concepts including blocks, miners, and nodes. Each blockchain contains a group of blocks, while these blocks have:

- ✓ A number called the first block;
- ✓ Genesis;
- ✓ A link to another through the hash of the previous block; and
- ✓ Data User.

These blocks are created by miners during a mining procedure. Miners apply a particular software in solving the math problem of incredible complexity, namely, to find an unprecedented value that creates an acceptable hash. Since the nonce has only 32 bits and the hash value has 256, nearly four billion indivisible combinations are possible and need to be extracted before finding the correct combination. The node in the blockchain has its own version. Blockchain chains are constantly updated after verifying that each node is registered within in the chain [16]. There are several types of blockchain technology, the most important of which are [17]:

- ***Public Blockchain***: They are chains that are open to the public in which any individual could become a member and can participate in decision-making. No participant has a ledger, as they are available to everyone in this type of blockchain. The instructors use a distributed consensus mechanism in decision-making to keep a copy of the ledger on their contract.
- ***Private Blockchain***: This type is not available to the public, as it is only open to a group of people and the ledger is shared with participating members only.
- ***Semi-Private Blockchain***: In this type of network, some parts of the network are organized and managed by a group, and other parts are available for the public to participate in.

Currently, Ethereum is considered to be among the most influential platforms that use blockchain in healthcare research. Similar to Bitcoin, Ethereum is a blockchain network of public distribution. Among the many ways in which these two differ technically, the most significant one to consider is that Bitcoin and Ethereum do not share the same purpose or capacity. Ethereum tends to the programming code for any decentralized application, miners work to earn Ether, a type of token that feeds the network, rather than Bitcoin. Beside the gradable cryptography, app developers used Ether for paying transaction costs and services within Ethereum networks. This platform shows a computer code called a smart contract that runs on the Ethereum virtual machine. Such a decentralized "global computer" has Ethereum nodes which provide the computing power. The contract that provides computing power for a particular resource is paid in form of Ether tokens. They are called smart contracts because the written contracts will automatically execute whenever requirements of the blockchain technology, it has taken wide attention to its application in various fields until it extended to the health sector. Taking into consideration the importance of blockchain in healthcare, the Office of the National Coordinator for Health Information Technology organized a contemplation challenge in 2016 to obtain white papers on the possible applications of blockchain technology within healthcare, which led to multiple proposals for using blockchain in the health sector. Despite that the storage of health records in blockchain can be considered as a case of healthcare use, yet there are a number of issues in implementing it, such as privacy issues, compliance with regulatory requirements, and technical obstacles to storing and distributing data [13].

III. BENEFITS OF BLOCKCHAIN TO HEALTHCARE APPLICATIONS

This section presents the major benefits of using blockchain in healthcare applications, as shown in Fig. 1.

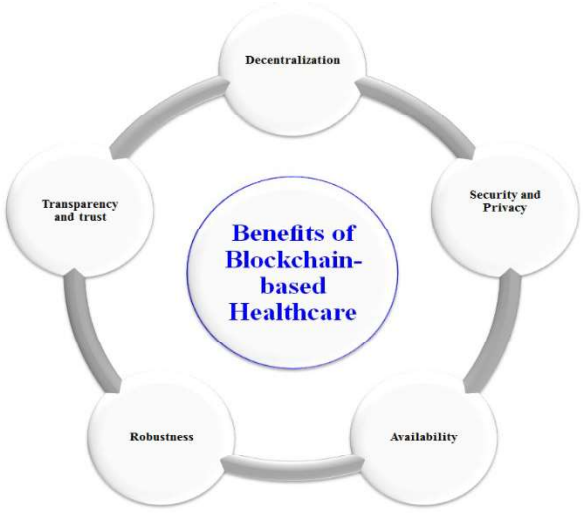

Fig. 1. Benefits of Using Blockchain in Healthcare Applications

A. Transparency

Transparency is one of the reasons why many argue that the blockchain can be used as a new standard of transparency. Advances in cryptography have allowed for much greater verification of the technology behind the blockchain, which means that more users are starting to trust the network [18]. As healthcare is an important industry, ensuring a well-structured methodology and transparent processes is crucial. Furthermore, several advanced security measures and a total accuracy are of equal importance. Blockchain technology provides both the integration of healthcare information and the maintenance of traceable records of distributed and business data. In addition, accessing the public/private key protects public security in a strong way through the elimination of data leaking chances. Blockchain also makes it easier to track drug movement from product to patient. Aside from ensuring timely supply, it also eliminates chances of fraud [19].

B. Decentralization

In Blockchain, decentralization refers to the transfer of control and decision-making from a centralized entity (i.e., individual, organization, or group thereof) to a distributed network. In a decentralized blockchain network, no one has to know or trust anyone else. Each member of the network has a copy of the exact same data in the form of a distributed ledger. If a member's ledger is altered or corrupted in any way, it will be rejected by the majority of the members in the network [20] Blockchain technology makes storage of medical data more secure and reduces risk of data fraud. The decentral and immutable characteristics of blockchain technology, together with smart contracts and custom transactions, provide the perfect foundation for developing a blockchain-based solution to store data that cannot be changed or tampered with, and which malicious hackers cannot threaten to delete [10].

C. Security & Privacy

The definition of blockchain could be described as protecting the transaction information and data in a block (regardless of its type) against internal, peripheral, malevolent, or unintentional threats. Such a protection usually involves detecting and preventing threats, as well as a suitable response to the threat by means of security policies, tools, and IT services. The privacy of blockchains can be stated as the extent to which a single person or a group cis capable of secluding themselves or data, and thus express themselves in a discerned way. It includes the ability of performing transactions with no leakage of identification information. It also allows users to remain compliant through discerning self-divulgence with no showcase of actions to the whole network [21].

D. Robustness

In fact, blockchain is built-in robustness and durability functionality. There is no aspect of failure because of its distributed nature. It is beyond failure from the part of humans or the system. The only form of failure has been caused by hacking or human error; meanwhile underlying technology still holds strong. It operates in the following way: there is the main register that records a transaction, and a connected and distributed system of registers also records this transaction. The connected registers are secured and validated [22]. Blockchain technology guarantees robustness especially in detecting system for counterfeit drug in the pharmaceutical supply chain [19].

E. Availability

The availability of blockchain systems indicates their ability to withstand interruptions and attacks. The information must be available in all participating nodes without any failure. This is rooted in the distributed nature of blockchain technologies. The system must have the ability to handle high loads in its working condition. Blockchain ensures continuous availability and access to real-time data, where the latter improves coordination and thus enhances clinical care in cases of medical emergencies. It also helps researchers and public health resources in fast detecting, isolating, and driving changes to environmental conditions which influence the public health [23].

IV. Classification of Blockchain-based Healthcare Applications

The most important studies related to either in the electronic health record system and the remote patient monitoring system that using blockchain technology are introduced as shown in Fig. 2.

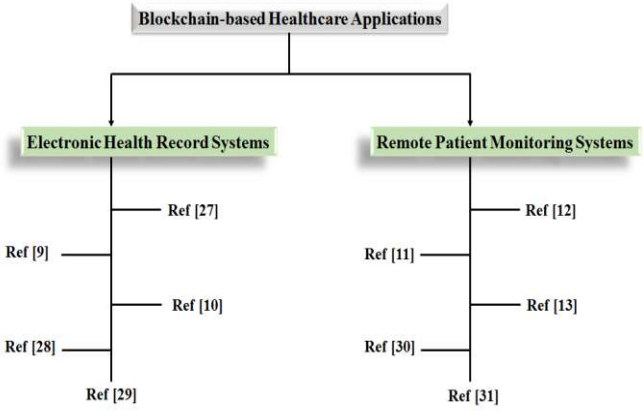

Fig. 2. Classification of Blockchain-Based Healthcare Applications

A. Electroinc Health Record

- *Using Blockchain for Electronic Health Records*

Aisha Shahnaz *et al.*, [24] presented a conceptual model to use blockchain technology in solving security and integrity issues of health record data, as well as to manage it. This system uses a smart contract and the Ethereum platform for storing the health record data in the blockchain. As for the blockchain algorithms, the system used the Proof of Work (PoW) algorithm that relies on consensus between nodes to complete the transaction. For the user layer, the system depends on the use of the browser that contains the graphic user interface (GUI) for decentralized applications. To evaluate the system, the researchers used the treatment execution time, throughput and latency. The purpose of this scenario is to safely store health records through the definition of precise access rules for the users of the proposed framework.

- *Secure Electronic Medical Records Storage and Sharing Using Blockchain Technology*

Othman and Qamar [25] presented a mechanism for using the permissive blockchain technology (*Hyperledger*) for solving the issue of data manipulation in electronic records. The system proposes to use the Ethereum platform and smart contract to manage the electronic health record, as there will be management of the process of registering users (patients or doctors) in the system by the health administrator. Each user is given an identification number and a secret key for the purpose of entering the system. The system allows patients to control who can see their data. The system was evaluated on the basis of using permissioned blockchain technology compared to using *permissionless* blockchain, as the author states that the problems related to the entry of unidentified persons, the possibility of data being visible to all, and other problems in the use of *permissionless* blockchain as a reason to replace it with the permissioned blockchain technology and

evaluate performance on the basis of the comparison between these two systems.

- *MedRec: Using Blockchain for Medical Data Access and Permission Management*

A model for implementing the concept of decentralization in electronic health record data management according to using smart contracts on the Ethereum platform was introduced by Azaria *et al.*, [26]. The model was applied to record the relationships between patients, doctor and healthcare providers on the blockchain. The proposed model demonstrates a new approach for handling medical records, which provide auditing, interoperability and accessibility across a comprehensive registry. The model enables sharing patient data and incentives to medical researchers for maintaining the system. The proposed model relies on a set of smart contracts related to user registration, linking the relationship between them, and keeping backup copies of records in case the patient leaves the system and then goes back to it. Thus, it allows patient data to be shared with service providers. MedRec will be responsible for granting authorized access to the system.

- *Blockchain-based Electronic Healthcare Record System for Healthcare 4.0 Applications*

Tanwar, Parekha, and Evans [27] introduced a mechanism for using the distributed ledger technology provided by the blockchain to implement a system for sharing e-health records based on giving permission to use the concept of the serial code. The system proposes building an algorithm for access control policies with symmetric key encryption for achieving privacy of patient data in electronic records. These records will be updated and can be seen by any user within the blockchain network. Service providers, such as physicians and laboratory personnel, could request any needed data over the network. Whenever a patient is granted access to see and update their records in the larger network of electronic health records, then the doctor or laboratory participant could access and update it in case the need for patient permission records arises. Researchers compare the blockchain-based system to traditional systems that rely on a client-server system with regards to throughput and latency.

- *A Proposed Solution and Future Direction for Blockchain-Based Heterogeneous Medicare Data in Cloud Environment*

Harleen Kau *et al.,* [28] presented a conceptualization of a building mechanism that integrates blockchain technology with the cloud in order to quickly and securely access user data in the electronic health record and manage heterogeneous data. The system suggests that the user submits a request for conducting transactions. The request is sent to the blockchain-based cloud and verifies the user's identity with crypto credentials. The verification is followed by the system processing the request to store, process, transfer or retrieve medical data from the network. The verification of a granted request adds a new block to the existing blockchain which includes the information of the particular transaction as well as the new state of data. The user is provided with the requested information or data, and the transaction is thereby completed. In this form, an outline of the framework, internal workings and protocols for dealing with heterogeneous healthcare data is provided.

B. ***Remote Paithant Monirering***

- *A Decentralized Privacy-Preserving Healthcare Blockchain for IoT*

Dwivedi *et al.,* [29] introduced the concept of using symmetric and asymmetric key cryptography with lightweight encryption algorithms that include a digital signature to protect data, as well as using blockchain technology to transfer data for Internet of Things (IoT) in form of a transaction using smart contract provided by Ethereum and associated to the blockchain. The researchers suggest storing data in the cloud for easy access. The proposed system is protected by blockchain technology. The system was evaluated on the basis of confidentiality, integrity, availability, as well as authorization. The researchers in this system aim to create a new framework for a modified Blockchain model to suit the nature IoT devices that make the data of these devices secure and anonymous according to the blockchain network.

- *Healthcare Blockchain System Using Smart Contracts for Secure Automated Remote Patient Monitoring*

Griggs *et al.,*[30] presented a model for creating a system to link medical sensors with smart devices that would be linked to smart contracts to compare the threshold to the data sent to it, and then write the events into the blockchain. The smart contract enables real-time patient monitoring. The purpose of the proposed system is to make sure that the data security is provided according to the Health Insurance Portability and Accountability Act (HIPAA). The authors propose integrating wireless body area networks (WBANs) with a smart contract on a blockchain managed by a consortium to process and store data created between WPANs and healthcare providers. The system was evaluated on the basis of the blockchain characteristics of confidentiality, integrity, immutability and transparency.

- *Softwarization of Internet of Things Infrastructure for Secure and Smart Healthcare*

Salahuddin, Al-Fuqaha, and Guizani [31] proposed a model to build an agile software infrastructure that relies on Software Defined Networking (SDN) and Network Function Virtualization (NFV) for spreading the Internet of Things (IoT) to smart healthcare applications and services flexibly and securely, while being cost efficient and preserving privacy. It integrates the latest network and virtualization technologies over the Internet of Things, hazy domains and the cloud, using Blockchain, Tor and message brokers for providing a secure and private environment to patients and healthcare providers. Also, the authors proposed a new platform through the use of machine-to-machine messages (M2M) and rule-based beacons to seamlessly manage data and elaborate the role of data integration and decision in cloud and fog, respectively, in smart health applications and services.

- *Internet of Things Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceutical Prevention*

Singh, Dwivedi and Srivastava [32] presented a mechanism to create a system that adopts cryptographic algorithms and blockchain technology to monitor temperature so as to ensure that medicines are not damaged. They use the sensors of Internet of Things devices to measure the temperature. The authors suggested using a blockchain-based system to monitor the drug supply chain to prevent the entry of counterfeit drugs, as the blockchain only stores the supply chain event when the actual data is stored on the distributed cloud. The latter is found in form of identical blocks that are linked to a unique block number. Such clouds are linked to both the peer network and the bloXroute servers. The calculation of hash of data is performed by meand of the Merkle Tree structure, where each Merkle root block is unique. This structure is stored upon the blockchain. Any data alteration can be easily tracked using the blockchain, and thus the suggested framework requires no full trust from a third party.

- *Continuous Patient Monitoring with a Patient Centric Agent: A Block Architecture*

Uddin et al. [33] represented a model for a patient-based healthcare structure. It consists of a BSN, smartphone (sensor data provider), central patient agent, blockchain, and healthcare provider interface. A number of communicating channels are found from one end of the structure, like BSN to Smartphone, Smartphone to PCA, and PCA to Blockchain. The proposed structure consists of two levels; the lower level will provide the data flow as well as storage solutions, while the upper level will manage the healthcare provider switches, also known as Healthcare Console Unit (HCU). The lower level consists of six systems, including Body Area Sensor Network (BSN), Sensor Data Provider (SDP) like smartphones, Central Patient Agent (PCA), Blockchain, Healthcare Provider Agent (HPA) and Healthcare Provider Wallet (HPW). The BSN will be linked to the PCA by means of a sensor data provider like a smartphone. A connection is created between the PCA and each of the Blockchain, Cloud, and Healthcare Console network. The HPA provides a connection between Blockchain, HCU, and Healthcare Wallet at healthcare provider end. The structure has been designed to accommodate large numbers of patients. The system was evaluated based on the analysis of proposed attacks, including man in the middle attack, replay attack, and denial of service attack.

V. Challenges of Blockchain-based Healthcare Applications

In this section, many challenges faced in applying Blockchain-based healthcare are highlighted.

Comprehensiveness: In reviewing previous research related to the use of blockchain technology in health care, most of them talk about either electronic health record systems or a remote patient monitoring system. In other words, research suggests building health care systems using blockchain technology for a part of health care and is thus not comprehensive for all parts of health care. This may cause trouble for users as they just have to use different applications to access the two systems. Therefore, in future research, there is a need for proposed systems to be comprehensive for health care, that is, there is a system that proposes to merge the electronic health record and the remote patient monitoring system into a single system linked to Blockchain technology.

Cost: As is known, technologies of Blockchain charge the amount of fee for transactions and utilize it to compensate the nodes included in the agreement process. The healthcare records somehow cannot store all the patient data to such a Blockchain, because putting the data to a Blockchain contract requires a transaction fee. So, in case of requiring placing data of a particular patient record as well as the data gathered from IoT devices on such a blockchain, then it may be required to aggregate it, so as to decrease the transaction fee. For that purpose, it will be important to ensure that the compilation process does not exclude basic information.

Data Management: In the references for example [25][26], the entity responsible for managing and entering data is an organization or person. The important question to be raised is regarding the difference between these systems and the traditional centralized systems, as there are people who control both data entry and the system. As the purpose of using blockchain technology is to create decentralized systems that people or organizations have no control over, therefore in the case of thinking about building a decentralized system based on blockchain technology, there should be no control of individuals or organizations over it.

Globally and Locally: It is expected that ubiquitously IoT-based healthcare data generated from patients will in turn generate large quantities of data. This data of IoT could exhibit strong locality and heterogeneity and would be useful to local places (hospital or clinic) only. On the other hand, may require sharing Blockchain-based healthcare for IoT networks between various sectors for allowing transactions to be treated in parallel. This serves as the opportunity to develop sharing Blockchain-based healthcare for IoT networks. So, a primary Blockchain could be developed for capturing significant yet limited frequent global transactions of interest across large Blockchain-based healthcare for IoT networks. Furthermore, Blockchain could be developed for recording frequent local transactions of interest only to local networks.

Security and Privacy: In the references for example [30][29][33] the research focuses on protecting the network rather than individual nodes. In the event that there is an adversary within the network, this will cause problems concerning how secure and private the remainder of the nodes are within the network. Therefore, considering the establishment of a system that adopts blockchain technology, it is important to think about protecting the nodes in addition to the network.

Delay: Healthcare applications based on IoT depend on a collection of data on patients that record according to the patient case and data consumers that are represented by doctors. So, in some cases, data consumers respond to action and perform an actuation. In such a case, the initiation of Blockchain technology may decrease the responsiveness when the data consumer requires set for the completion of the consensus operation before replying to an action. Modern technologies are not suitable for time sensitive IoT

applications, for example patients monitoring (heart rate and blood pressure) by IoT devices that require fully confirmed transactions.

Confidentiality: In reference for example [28], the patient data is visible to every user on the blockchain network. Since health data is very sensitive, this procedure may lose the confidence of some users who do not want to disclose their data. Therefore, when choosing to use blockchain technology in healthcare, the private blockchain networks must be chosen instead of the public one.

VI. CONCLUSION

Healthcare research concerning the application of blockchain technology has been increasing over recent years. This gave rise to becoming a very interesting field of researchers. Although there were many good reviews that had been presented; still more investigation is needed in this domain. This study focuses on using blockchain technology either in the electronic health record system or the remote patient monitoring system as a new study classified the methods regarding these issues. In this survey, the most important studies have been chosen, which are related to these two systems, and an explanation of the processes of the proposed methods, strengths, and weaknesses of each one has been provided, too. Moreover, various challenges related to this topic were introduced, which may assist researchers, healthcare providers, and developers to point and address them in the future. Also, the future works will be extended to cover more Blockchain-based healthcare techniques deeply.

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