Blockchain-based Remote Patient Monitoring in Healthcare 4.0

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***Abstract*—In Healthcare 4.0, Remote patient monitoring (RPM) becomes a more powerful and flexible patient observation through wearable sensors at any time and anywhere. The most focused application area of RPM which allows doctors to get real-time information of their patient remotely with the help of wireless communication system. Thus, RPM reduces the time and cost of the patient. It also provides the quality care to the patient. To enhance the security and privacy of the patient data, in this paper, we have presented a Permissioned blockchain-based healthcare architecture. We have also discussed the challenges and their solutions. We have described the applications of blockchain. We also have given the usage of Machine learning with blockchain technology which can impact the healthcare industry.**

***Index Terms*—Wearable device, Blockchain, Remote patient monitoring, Healthcare 4.0, Machine learning, Decentralized AI**

I. Introduction

Healthcare is the major concern of any nation for its overall growth [1]. Healthcare is the improvement or maintenance of health through the diagnosis, disease treatment, prevention, injury, illness and other mentally and physically ill people which is delivered by doctors. The healthcare industry has revolutionized from 1.0 to 4.0. In healthcare 1.0, patient records were maintained manually by the doctors, which has the limitation of data redundancy and duplicacy [2]. Manual record management in healthcare 1.0 was replaced by an electronic record in healthcare 2.0 [1] It gives an easy access record to the doctors and also removes the data redundancy issue. But, the problem with healthcare 2.0 is that it is more doctor centric, not the patient-centric. Later, this problem was solved in healthcare 3.0, which was patient-centric too. But, it is not able to handle a big amount of real-time healthcare data. So, healthcare 4.0 connects everyone to the WD's along with their locations.

Nowadays, every person required to visit the hospital for their regular checkups and diagnosis, which is a very costly and time-consuming process. So, a critically ill patient can't visit even to the nearest hospital. To overcome this problem, the healthcare industry introduces RPM, where patients deployed WDs and that collect real-time health information such as ECG, heart rate, temperature, blood pressure. This information can be helpful for doctors for the diagnosis purpose and with the help of decentralized AI they give suggestions to their patients for health issues. By this process, patients were diagnosed remotely by doctors [3] which improves the quality care of the patient.

The most challenging and focused application area of RPM is to get real-time information of the patient remotely. In the existing system, the real-time information gathered from the WDs and stored into a centralized cloud server. In a centralized environment, each node connects to the single node or central entity. In any case, if central entities fail then chances of losing information may increase. To solve this problem, take a backup of data and stored in the centralized cloud server. There was another problem like not protected from the various malicious attacks such as confidentiality-based, integrity-based, and availability-based attacks [4].

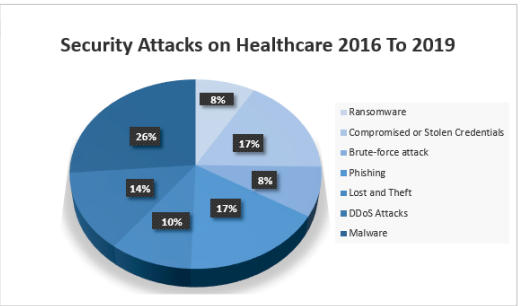

Fig. 1. Cybersecurity attacks on healthcare data 2016 upto 2019

Nowadays, attacks on healthcare data has increased. Fig 1 shows the attack percentage on healthcare data since 2019. The various possible attacks on healthcare data are Ransomeware, Compromised stolen credentials, brute-force, Phishing, Lost and theft, DDoS, and Malware attacks. Instead of attacks only, the other in centralized cloud server-based RPM systems are:

- Always not getting updated real-time information from the Cloud server.
- Not secured against the insider attack.
- Lack of transparency of information stored in the cloud server by patients, caregivers, and doctors [2].
- No digital agreement signed between the authorities such as healthcare providers and caregivers before the access of patients information [2].

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TABLE I
KEY FEATURES OF THE BLOCKCHAIN [3]

Key Features	Functionality Description
Decentralized	There is no central authority to control other entities.
Transparent	Each system which is connected to the Blockchain network. Everyone has an updated copy of the ledger for work on that updated copy. The transparent nature of blockchain could prevent modification in the information.
Immutable	The recorded information cannot be modified easily because of the advance cryptography (Hash functions)
Autonomy	The Blockchain system is autonomous and independent. Every node of the blockchain network, can transfer, store, access, and update the data securely, making reliable.
Anonymity	As any information transfer in a peer to peer network, the identity of the individual node remains anonymous, thus it making trustworthy and reliable.
Distributed	Spread over the different organizations and locations
Authentic	Different providers in the transaction have consistent, timely, accurate data.

Motivated from aforementioned issues of traditional healthcare RPM system. we have discussed the blockchain-based RPM system. Blockchain is a distributed ledger where multiple parties are connected and work together. It maintains the immutable log of transactions that occurred between the different participating members such as Doctors, patients, and caregivers which protects data tampering. Transactions are added based on the conditions satisfied by the digital agreement between different healthcare providers, patients, and caregivers. The consensus algorithms such as Proof-of-stake(PoS), Proof-of-work (PoW), Byzantine Fault Tolerance (BFT), Practical Byzantine Fault Tolerance (PBFT) ensures the data consistency in the blockchain. The Table Ishows the key features of the blockchain. blockchain allows doctors and patients to access the updated healthcare data instantly as each participating member of the blockchain is having a copy of the entire blockchain. The authenticity of data in the block of a blockchain can be well-taken care of by the smart contracts and consensus algorithm.

A. Contributions

The main contributions of this paper are described as follows:

- We highlighted the security and privacy challenges of the traditional healthcare system.
- We discussed the applicability and integration of blockchain and healthcare system.
- Highlighted the usage of machine learning in blockchain for enhancing the security.
- Finally, we describe the applications and challenges of blockchain.

B. Organization

Related work of this paper described in Section II. Section III describes the System Architecture. Section V, Discussed the challenges and applications of the blockchain in healthcare. Finally, the paper is concluded in Section VI.

II. RELATED WORK

In this section, we presented the survey of various in-depth state-of-the-art and traditional blockchain-based RPM systems. Nowadays, blockchain is applicable in many areas like bank, finance, and healthcare. We have focused on the Healthcare domain. There are many authors which have been done some work in blockchain-based healthcare. Here, we give an overview of that work. Author *et al.* [5] developed the data-sharing system by synchronizing the IoT and Digital ledger technology to enabling the secure, tamper-proof, and scalable at the time of health data exchange. Siyal *et al.* [3] reviewed the various application of blockchain in healthcare and medicine. Vyas *et al.* [6] gives a survey of integrated Blockchain and Machine learning in the healthcare domain. They have used the permission-based blockchain for review. Chattu *et al.* [7] presented the role of blockchain technology in a disease surveillance system. They have discussed how blockchain is useful to identify the threat in advance and send a report to healthcare organizations to taking preventive measures in advance. They have used the ML algorithms for a disease surveillance system. Zheng *et al.* [8] discussed various types of security constraints such as encryption, anonymous signatures, non-interactive zero-knowledge proof, secure multi-party computation, and secure authentication of smart contracts in a blockchain.

Uddin *et al.* [9] designed a (PCA) patient-centric agent-based continuous patient monitoring healthcare architecture. This architecture resists network attacks such as Sybil, man-in-the-middle, and eavesdropping attacks. Griggs *et al.* [10] proposed blockchain-based smart contracts for automated RPM. They have used a private blockchain with Ethereum. They have created a system where WDs are communicating with a mobile device and connect with smart contracts. This smart contract supports real-time monitoring of a patient. They had resolved the many security vulnerabilities in RPM. Leeming *et al.* [11] described an analysis of existing blockchain-based health-related solutions. They have expanded a personal health record to produce a bridge that combines the access of health data, digital innovation and collection with smart contracts. They have also created one ledger of me architecture-based on health records, patient control, and event-driven smart contracts used for the promotion of blockchain-based solutions in PHR. Nguyen *et al.* [12] proposed a EHRs sharing scheme on mobile-cloud platform. They have designed a reliable access control mechanism for patients, doctors and healthcare providers. They have used the Ethereum blockchain in real-time data sharing on a mobile application. They had preserved the sensitive information of the patient from malicious attacks. Srivastava *et al.* [13] described the automated RPM for data sharing in a blockchain environment with proof of work (POW). They have also used smart contracts for analyzing the patient's health-related information. In this paper, we surveyed some of the existing state-of-the-art blockchain healthcare schemes and discussed the integration of machine learning and blockchain with numerous advantages.

Table II presents a summary of the surveys and their differences with the proposed system by considering type of blockchain, applications and ML technique used, challenges of blockchain, and pros, cons of the existing approaches.

III. SYSTEM ARCHITECTURE

Blockchain is worried about keeping correct records of patient, execution, and authentication while AI is powerful in decision making, understanding and evaluating datasets and

TABLE II
SURVEY OF BLOCKCHAIN-BASED HEALTHCARE SYSTEM STATE-OF-THE-ART SCHEMES

Author	Year	Objective	Type of blockchain	Applications and technique used	Challenges based on security and privacy	Pros	Cons
Chattu *et al.* [7]	2019	To present the role of blockchain technology in the routine disease Surveillance system and global health security agenda (GHSA)	Permissioned blockchain	GHSA, Disease Surveillance system with ML techniques	Technical Challenges	Robustness, Real-time surveillance system, Early prediction	Regulatory and technical issues
Srivastava *et al.* [13]	2018	To demonstrate the automated RPM for data sharing and privacy using blockchain	POW based GHOSTDAG protocol	GHOSTDAG with Acyclic graph	Not given	Improves Scalability, Improves High throughput	Law-Interoperability
Uddin *et al.* [9]	2018	To describe the remote patient monitoring with a PCA	Not discussed	PCA	Not given	Resist Sybil attack, Man in the middle attack, Eavesdropping attack, Compromised key attack, DoS attack	Scalability issue
Griggs *et al.* [10]	2018	To present healthcare blockchain using smart contracts for automated remote patient monitoring	Permissioned blockchain	Ethereum protocol	Maintaining security at every individual node, Proper key Management	Transparency, Anonymous, Traceability, Speed, Availability, and Immutability	Authentication protocol are not addressed
Vyas *et al.* [6]	2019	To discuss the combination of machine learning and blockchain in healthcare	Permissioned blockchain	ML techniques used for disease prediction	Not given	Early prediction of disease, More accurate and efficient ML models	Scalability issue
Siyal *et al.* [3]	2018	To describe the applications of blockchain in healthcare and medicine	Not discussed	Diagnosis and treatment improvement of patient, brain-reading accuracy	Managing storage capacity, Interoperability, Security and privacy of patient	Irreversible transaction, Reduced transaction time	Scalability issue
Proposed	2019	Blockchain-based RPM using ML techniques	Permissioned blockchain	Improve the disease diagnosis through trained ML models	How blockchain can transform with AI and ML	Blockchain provides security and privacy of patient, To make a system reliable	

patterns, and autonomous seamless interaction. The decentralized nature of blockchain highlights the significance of data sharing between multiple users on a specific network and everyone can validate the process in a network. Same applied in decentralized AI which relies on big data, particularly on data sharing. Decentralized AI, get open data to analyze, predict, and check the accuracy of the trained model. To make a reliable system, we require to maintain the trust and security of data. In a blockchain, security is required to validate every transaction.

In this architecture, we concentrated on decentralized AI and also describe the application of RPM in a decentralized environment. RPM saves the time of patients because there is no need to visit the hospital. In an RPM, the doctor can gather the real-time information of the patient. This information useful in an early prediction of disease which helps to take preventive measures in a decentralized environment. In a decentralized AI, the doctor gives lifestyle advice to their patients with the help of RPM. That improves the quality of care of a patient in a decentralized environment.

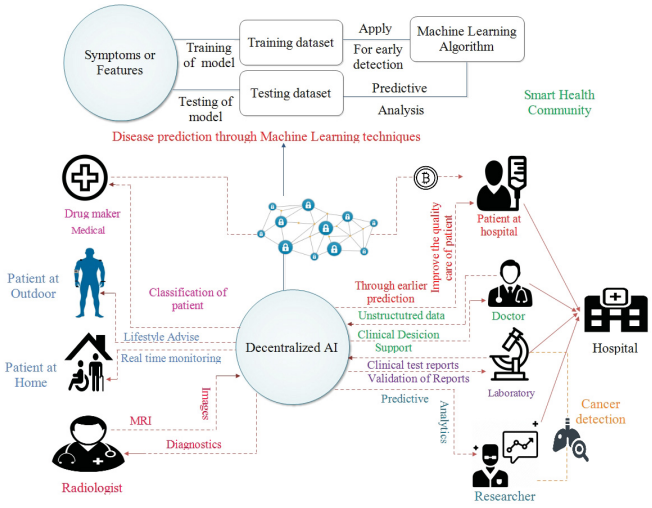

Fig. 2. Blockchain-based remote patient monitoring with ML techniques

Figure 2 shows RPM in decentralized AI. In this architecture, The outdoor patient and patient which available at home both have their WDs. These WDs are monitoring the real-time health-related parameter such as heart rate, blood pressure, the temperature of the patient. That measurements have shared in a communication channel with wifi and ZigBee standards. In a communication channel, there have a lot of chances to attack by adversaries. Then preserving the privacy and security of that data it is very challenging. To solve the issue, we have used the integration of decentralized AI and blockchain network which improves enhancement in medical research and healthcare domain [14] The combined features of these both technologies can play an emerging role in RPM. These features can help to improve the patient's quality of life by patients' routine exercise, reduce the level of stress measured through WDs in real-time monitoring and then gives the lifestyle advice to their patient. This integration also helps to improve treatment, customize medicine, and health-related suggestions which are based on the history of the patient, geography, past health conditions. The data stored securely on a decentralized or distributed and immutable record of patient as define in a graph-based database can be made for storing the unstructured data.

This architecture combined the decentralized AI and blockchain will make a great impact on a medical domain which adds the various parts such as analytics, diagnosis, validation of medical reports and decision making. In a Decentralized AI and blockchain network, multiple entities like hospitals, medicals, patients, doctors, laboratories, medical researchers, radiologists are connected. All entities have their different roles where the hospital is the main entity where all entities are connected. Other entities like the patient get a better quality of care with the help of decentralized AI. Decentralized AI uses multiple ML algorithms to train a model with symptoms or features which help to get an earlier prediction of disease. Then after medical researchers doing predictive analysis and that analysis helps to suggest to their patient. Decentralized AI provides clinical support to the doctor.

This architecture having two parts, where Blockchain is responsible to allow a patient to see their information and also have access rights. In a Permissioned blockchain, the patients have the access rights to decide who has access to their data. If any doctor having access rights of that patient then only that person should access their data. This process helps to make a patient-centric approach. For maintaining the security of the real-time data, blockchain uses the cryptography algorithms like RSA, SHA, and hash function where every block is connected through a previous block and one unique random number that can be very difficult to guess by an intruder or attacker. In this way, blockchain can preserve the security and privacy of patient's data.

At the hand, The information has received by the doctor who has connected in a blockchain network. They have no rights to access their data without taking permission from the patient. The first doctor can request the patient, if the patient allows accessing their data then a doctor can use their data for further process. A doctor gives a few suggestions for taking medicine, treatment, and others that have required for the patient. The doctor also can share a few diagnosis information to laboratories for a disease diagnosis of the patient which is a help to doing any treatment. Thus, RPM saves the time of the patient and get quality care at a very reasonable cost. That reason is helpful to attract people more about RPM. Nowadays,

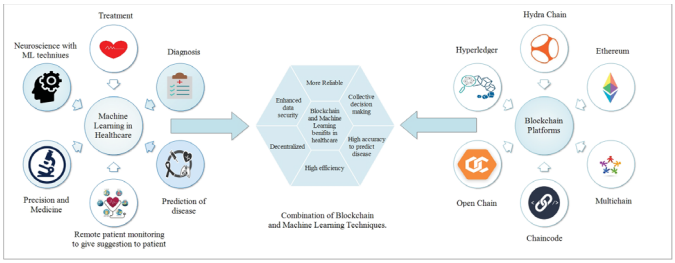

Fig. 3. Advantages of integration of machine learning and blockchain in healthcare [14]

Machine learning (ML) and blockchain both have emerging technologies, spreading in various domains. The integration of both technologies is impactful for the healthcare industry and big data analytics. There is a more significant procedure to help organizations to reduce the costs and improves the outcomes by leveraging data. These combining two emerging technologies can help them to solve the basic challenges of securely exchanging the big data that support the analytics Fig 3 shows the advantages of integration machine learning and blockchain technologies.

In the second part, decentralized AI can use the ML algorithms for early prediction of symptoms or disease prediction. In this process, First, give disease symptoms or features in a training data set. Then, some ML algorithms like Naive Bayesian, k-nearest neighbor and decision tree applied to that data. The model has trained through features or symptoms which had given previously. After, the model trained, give a testing dataset for checking the accuracy of that model. If a model trained successfully then accuracy is higher and classifies the label correctly and decides that label belongs to which class. This classification identifies the disease which helps to take preventive measures.

IV. Applications of Blockchain

In a digital era, preserve the data privacy of the patient is very crucial. For securing the data and improve the quality care of the patient must need to use the blockchain technology. This technology-shared, immutable data to a peer-to-peer node where transactions built from currently connected transaction blocks and stored in a digital ledger [15]. It has applied in various industries like banking, finance, and healthcare to protect data from an intruder. There are various applications like EHR medical, Genomics, biomedical, Pharmaceuticals, and laboratories available where blockchain has integrated with these applications. Fig 4 shows the applications of blockchain.

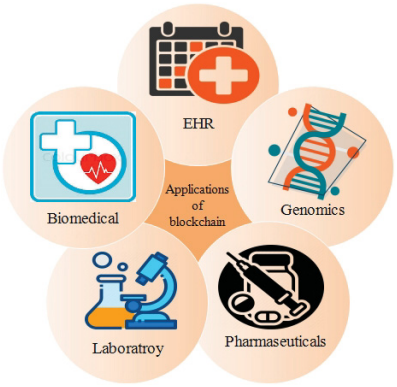

Fig. 4. Applications of blockchain

Following are the applications of blockchain in healthcare:

- Electronic Health Record (EHR): Decentralized ledger in EHR means that data cannot be held by any intruder. In a blockchain, each node has an updated copy of the ledger, and each node validated the copy [16] thus intruder can not get control all over the ledger. In a Permissioned blockchain, doctor, hospital, labs can able to access the patient's data after taking permission from the patient.
- Biomedical: In a blockchain-based medical application, alteration and replication were not allowed in a transaction. Blockchain only allows the secure and transparent transaction.
- Laboratories: Blockchain creates a secure decentralized structure for laboratory-related information which only happens with blockchain and that data can be shared securely with researcher groups [4].
- Pharmaceuticals: Blockchain traced the pharmaceuticals in detail and also keeps eye on every phase of the pharmaceutical supply chain of the medicine and its components are regularly detected at each phase to avoid the replacement of any goods [3].
- Genomics: Blockchain technology can help to create a genomics data revolution by reducing the individual genome

sequencing costs, democratizing genomic data ownership, and enabling transparent genomic data sharing. [17].

V. Research Challenges

In this section, we have discussed the challenges of blockchain and how these challenges addressed for research. We have given the solutions to a particular challenge. Fig 5

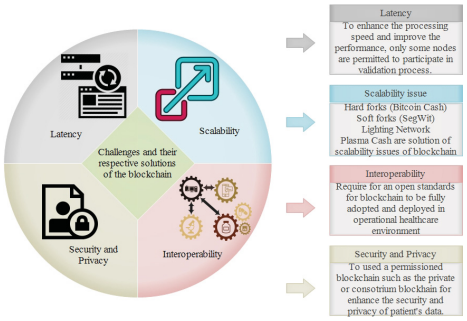

Fig. 5. Challenges and their solution of blockchain [18]

shows the challenges of blockchain as well as their solutions.

- Latency: In a public blockchain, all nodes are participating in the validation process which takes more time. To solve this problem, only a few nodes allowed to participate in the validation process which preserves time so improve the processing speed as well as the performance of the system [18].
- Scalability: There are various solutions available like Hard fork (Bitcoin Cash), Soft fork (Segwit), Lighting network, and plasma cash where we have used this solution to solve this problem.
- Interoperability: Nowadays, developers more focus to test features of the blockchain prototypes. There is a need to define interoperability for an open standard so blockchain deployed and adopted in an operational healthcare environment. In this environment, open standards guaranteed the interoperability between different products of blockchain [18].
- Security and Privacy: In a Permission-less blockchain, Intruder has a chance to attack in a network and create a major problem. To solve this problem, we required to use a Permissioned blockchain like a private or consortium blockchain to secure the data and preserve the privacy of the patient. Blockchain uses the smart-contracts which allows the execution of transactions without considering the third party user. These transactions are irreversible and traceable [18].

VI. Conclusion

In this paper, we provide insights to the blockchain-based RPM system for healthcare sector. The survey is by companioning it with existing state-of-the-art approaches. The second part of the survey, presented the blockchain-based system architecture to overcome the security and privacy issues of traditional system. The third part of the survey, focused on the various challenges of the blockchain. Finally, we highlighted various research challenges of blockchain in healthcare sector. In future, different doctors, or caregivers from different organizations will collaborate for giving proper diagnosis.

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