Employment of Blockchain Technology in Medicinal Segment

Nishtha Rawat[1*], Seema Rani[2*]
{nistha.rawat@galgotiasuniversity.edu.in[1], seema.rani@galgotiasuniversity.edu.in[2]}

Department of Computing Science & Engineering, Galgotias University[1],
Department of Computing Science & Engineering, Galgotias University[2]

Abstract. Blockchain technology has provided a better and safe solution for distinct problems in different segments. In the digital world, one and all are looking for solution that are simplified and secure. One domain among them is medicinal segment. The blockchain facilitate and provide solution in this segment from various perspective. The paper highlights the basic terminology used in blockchain platform and describes the flow of work using this technology. This study addresses the system in medicinal segment prior to blockchain and how blockchain influencing the medicinal segment in terms of solution from various aspects. The organizations using block chain technology in healthcare domain are reported in the paper. This examination provides the motivation for researchers to carry forward and search for new solution to employ the technology for ease of an individual in healthcare domain. Moreover, key challenges addressed in respect of medicinal segment gives direction for future investigationhe abstract needs to summarize the content of the paper.

Keywords: Blockchain, Medicine, healthcare, Supply chain, Pharmaceutical, Secure transaction.

1 Introduction

Blockchain technology bringing revolution in view of secure solution to many problems and opening new windows for research and innovation. The benefits of blockchain in segments like finance, internet of things, railway and energy segment is immense and further researchers are continuing to make the best possible use of this technology for providing the solution to many problems. One such segment that has the potential of getting immense benefit from blockchain technology is Medicinal segment. This paper introduces the basics of blockchain and it's working in medicinal segment along with benefits and challenges in implementation. All aspects related to medicinal segment has been taken into consideration which includes stakeholders - manufactures, suppliers, pharmaceuticals, research organizations, companies, service providers - doctors, care givers, nurses etc, end users like patients, and in outbreaks situations like covid-19.

Blockchain was coined by Satoshi Nakamoto in 2008 as his invention of cryptocurrency system named as Bitcoin. This was the beginning of electronic payment scheme and revealed the potential of Blockchain technology. Subsequently, the Blockchain technology has shown immense potential in various different fields like business, finance and medicinal segment. Blocks are connected in the blockchain network through a link where each block comprise of

valid transactions. These transactions exposed the progress of an asset either tangible (a product) or intangible (intellectual). Also, a larger block is required if number of transactions inside a block increase. The transaction can be initiated by any node present in the network and then can be forwarded to all other existing nodes in that network. Validation of transaction is done through algorithms. Once the validation is accomplished the respective transaction will be included to the existing blockchain [1].

Blockchain domain has immense potential to give attention to counterfeit drugs in supply chain and pharmaceuticals, combating outbreaks, secure sharing of Electronic Health Records (EHR), secure payment for patients and healthcare providers, secure gateway for companies and organizations for faster verification of patient's medical insurance claims, providing research organization platform to access medicinal data for academic research. However, the patients get benefit with digital currency as bonus or encouragement for their contribution, fake news detector to control situations during outbreaks, easy staff recruitment through access of validated academic documents and credentialling medical staff members etc. Blockchain technology can enhance the positive experience for all users related to medicinal segment field like stakeholders including insurance companies, pharmaceutical companies as well as the end users like patients, researchers and care givers [2].

Blockchain technology is capable of resolving challenges for the reason that: (i) It is distributed and not own by any single entity. This ensures decentralization, robustness and access control. (ii) It ensures data is cryptically secure. (iii) Information in blockchain cannot be changed or altered. This ensures immutability of transactions and data integrity. (iv) Blockchain is transparent and thus ensures nonrepudiation [3].

The paper is planned and structured in six sections. Section 2, introduces the commonly used terminology in the blockchain technology. Section 3, describes the related work in healthcare sector. In continuation, section 4 highlights that how blockchain play a role from different stakeholders' viewpoint in healthcare sector along with various applications. This also discourse the use of blockchain technology by different organization and reveals the continuous practice in order to provide the solution to different problems. This paper study recognizes, how blockchain works and benefits from stakeholders' aspects in the domain of medicinal segment. Section 5, discusses the challenges faced in implementation of blockchain technology. Finally, section 6 presents the conclusion along with future directions.

2 Fundamental of Blockchain

This section will help in getting acquainted with the elementary components of the Blockchain domain.
- Block – The collection of transaction is contained in a block. It is a unit of data or record. A blockchain is formed by combining many other blocks arranged in a specific order.
  Each block has 3 basic elements along with data [4]:
  o Hash – To make blockchain secure hash is used which identifies block and all its content uniquely.

o Nonce – It is an abbreviation for "number only used once" which is a number added to a block. It is a 32-bit whole number generated randomly at the time of creating a block.

o Time stamp – It indicates the time when the actual block was created.

At the time of creating the first block in a chain, a nonce generated by the cryptographic hash. The data in the block is recognized as signed and endlessly tied to the nonce and hash unless it is mined [5].

- Blockchain – It is a chain of blocks in which each block is linked to the previous block's data as depicted in Figure 1.
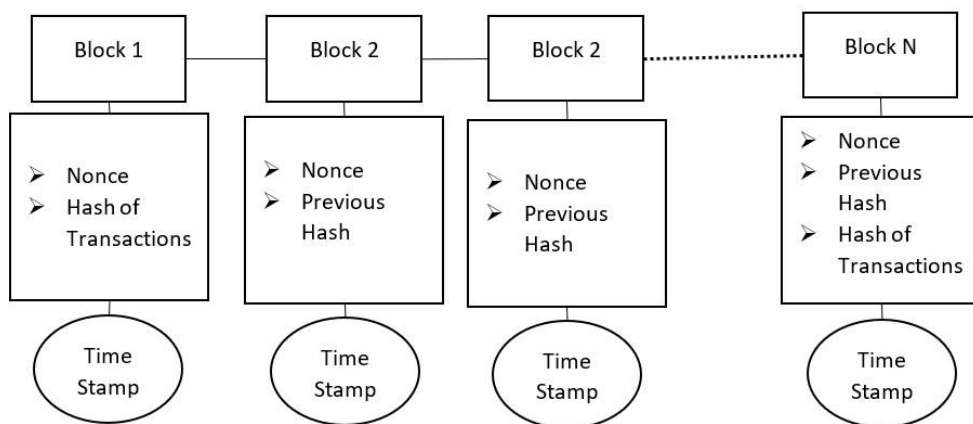

Fig. 1. Blockchain

The essential requirements for blockchain for its working are:

o Peer-to-peer (P2P) network – A network of computing nodes that collectively work on transaction in a network.

o Cryptography – For validation and authentication of transaction, cryptography encryption is used.

o Consensus algorithm – These ensure that the participating nodes in a network agree on some rules for adding a block. Thus, ensures authenticity.

o Reinforcement in form of reward and punishment – This ensures all nodes follow the rules for best outcome [3].

- Miner – It is a blockchain user or nodes who along with other blocks do validation and solve complex problem of creating new blocks in the chain through a process called mining, subsequently it is financially rewarded.

- Ledger – It is a record of transactions which can be tracked and analysed over a period of time. It documents the transfer of ownership and authenticating ownership. In other words, ledger is defined as a book of record keeping all the financial transactions of the organization. The basic terminology of blockchain described a ledger which is a record of transactions that can be tracked and analysed over a period of time. Below is the description of two types of ledgers: (i) Centralized ledger, (ii) Distributed ledger.

Fig. 2. (a) Centralized   (b) Distributed
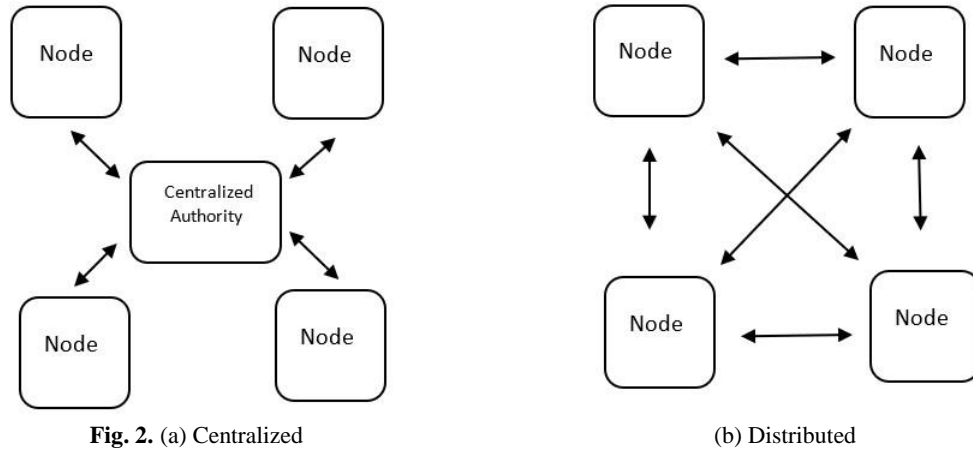
A centralized ledger as in Figure 2(a), is also known as general ledger in which there is a central authority for controlling and recording transactions. The drawback of centralized ledger is that it has a single point of authority. So, dependency on the centralized authority increases and is prone to failure and is insecure [6].

A distributed ledger as in Figure 2(b), is a chain of blocks comprising of explicit number of valid transactions with their time-stamped. Blocks are linked cryptographically using the hash value of the previous block. In distributed ledger there is no central authority. Each participating node has an identical copy of the ledger and it can be updated independently. A single truth copy of the ledger is maintained through some consensus algorithms that make sure all participating nodes agree on it. Further, this latest truth copy is automatically added on each node separately. This ensures that updates are made by node separately on the latest truth copy. This method, does not have central point of failure and more secure as trust is maintained [2].

Following section 3, provides brief discussion of the existing and available literature or use of blockchain technology in medical segmenthe main text should be written using Times New Roman, 10pt, fully justified. Italics can be used for emphasis and bold typeset should be avoided.

3 Related Work

The available literature with that using and implementing the blockchain technology in medicinal segment is relatively few as compared to application of blockchain technology in other segments like finance, internet of things, security and energy segment. A few papers have provided the details of benefit of applications in medicinal segment, while an overview dedicated to medicinal segment is missing in most recent research papers. Such as, the work presented in year 2019 provides a detailed classification of applications in healthcare for blockchain technology with technical aspect added, however it misses the basic working related to blockchain terminology [7]. With a similar work in year 2022, the vision of blockchain in healthcare sector has been described. The possible areas where blockchain can be promising in

healthcare sector is mentioned along with its benefits. However, the working of blockchain is not much explained [3].

In the year 2020 the paper identified challenges and opportunities related to implementation in blockchain technology in healthcare although they excluded the working part of blockchain [8]. Along with the same line of work in the year 2021, reviewed papers to answer key points related to blockchain technology in healthcare domain. Challenges and its probable solution to implement blockchain in existing healthcare system is discussed [9].

In the year 2021 the work provided the ongoing research for Covid 19 and the technical terms related to blockchain. However, their paper does not contain more information related to technical aspect of blockchain [1]. In the same year with similar work, provided a detailed study of many papers and extracted the important ones that have either implemented blockchain technology or have provided some methodology for the same. The paper focuses more on the working of blockchain in the outbreak scenario of healthcare [10].

In the year 2019, the paper explained the working of blockchain through a scenario and example that provide insight towards its implementation in different sector. However, the application part related to blockchain is not addressed [2]. Similarly, in the year 2020, the work presented a systematic review of papers related to blockchain that relates to its implications, implementation and gaps in healthcare sector. However, the basic terminologies related to healthcare is missing [11].

In this paper, an effort has been made to cover all aspects related to medicinal segment viz manufactures to companies, to service providers doctors, care givers, nurses, to end users like patients till supply chain and pharmaceuticals along with outbreaks situations. Subsequent section 4, gives the viewpoint how blockchain technology will improvise different services or segments of healthcare domain. Also, the organization which are currently making use of blockchain technology from different stakeholder's point of view.

4 Blockchain in Medicinal Segment

Health care segment involve a wide set of stakeholders which exist inside and outside the organization, both. The stakeholders play a vital role in operation and maintenance in all the domains. With respect to the domain of study, key stakeholders along with the communication or relationship among different entities are shown in Figure 3.
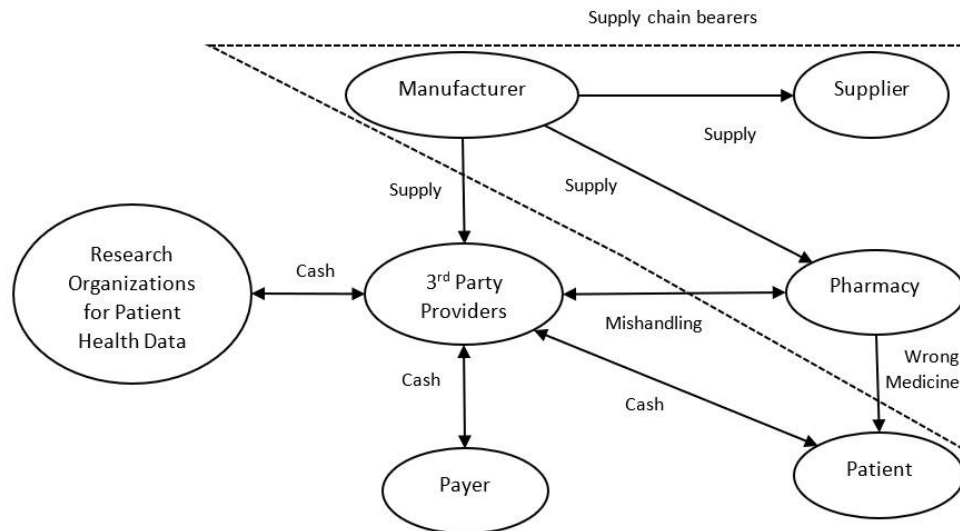
Fig. 3. Relationship among five major stakeholders in medicinal segment

Figure 3 describes the relationships that most commonly exists among the stakeholders in medicinal segment. The stakeholders include:

- 3rd party providers can include hospitals, care givers, doctors, specialists, nurses and other institutions that provide services like dental, domestic health, surgical, medical, residential, educational, ambulatory and diagnostic laboratories etc.
- Patients contacts the providers for the services they are providing by paying for the services. In this process patient health data is recorded by the providers based on the diagnosis recommended by the providers. However, patients have less control on the access rights of their health data.
- Payers includes insurance companies or organization that provide health and benefits to its employee or customers. These payers pay the claim to providers on behalf of the patients.
- Research organizations use patient's data generated by providers to find more solutions to existing health problems, academic research and pharmaceuticals. Only concern is that patient data shared with these organizations are without the permission of patients which is the violation of patient's privacy. Also, providers get monetary benefit for sharing health data with research organizations.
- Manufacturers, supplier and pharmacy are part of supply chain bearers. These plays a major role in supply chain that involves a range of activities like drug ingredients, production, storage and distribution. Manufacturer supply the drugs to supplier, pharmacy as well as 3rd party providers thus, involvement of different sources during drug transportation can lead to production of counterfeit medicine.

Similarly mishandling of patient prescription by 3rd party provider to pharmacy can result in wrong medicine being delivered to patient. Also, patient prescription being sent to the community pharmacies can lead to data privacy issues. [2].

To overcome the issues generated from interactions of different stakeholders in medicinal segment, blockchain technology can be used to provide a layer of privacy and security. With blockchain, a platform can be provided that will help all the stakeholders and will provide an environment of privacy and security to both medicinal segment applications and the blockchain technology being used in them. The following Figure 4 represents a comprehensive view of blockchain working in medicinal segment.
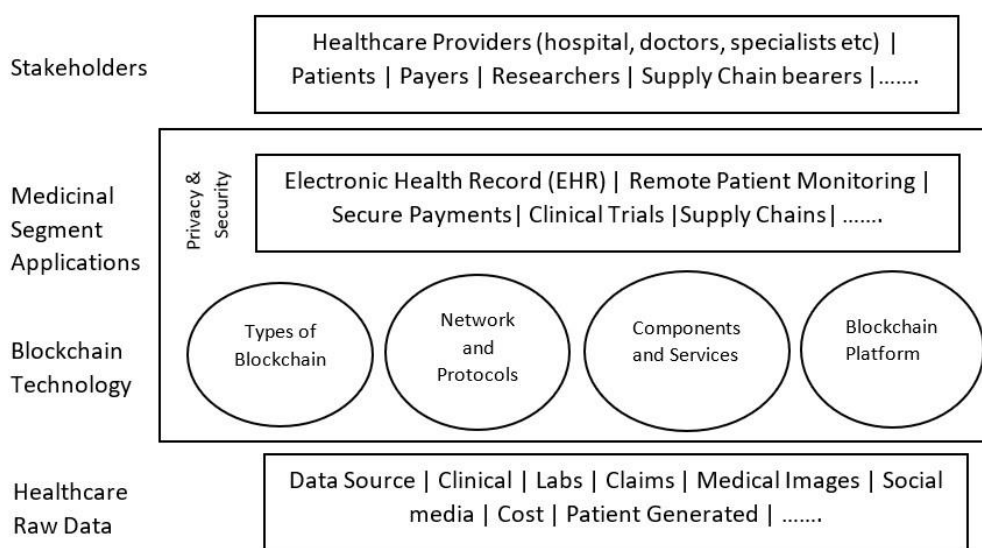

Fig. 4. Overview of blockchain in Medicinal Segment

It shows how multiple stakeholders benefit from blockchain-based applications along with privacy and securiy. Figure 4 shows the implementation of blockchain at a level in between healthcare raw data and healthcare applications. The top layer is the stakeholder layer, these are the ones who are getting benefit from implementation of blockchain in healthcare domain. This consists of several parties as a subset of the five stakeholders (provider, patient, payer, research organizations, and supply chain bearers) as explained in Figure 3. The top most layer parties get benefit in terms of security, authenticity, transparency, and streamlined transactions while sharing of medical or healthcare data and managing data with ease. This reduces the margin of fraud and eliminate the third party [7].

Following subsections will convey about different services which can be further augmented with blockchain technology. It briefs about the system with and without blockchain along with the organization which are making use of blockchain technology in catering the services related to medical sector.

4.1   Application in Medicinal Segment

In medical sector, many stakeholders from inside and outside the organizations are involved. Each stakeholder either takes a service or provides a service. Following Figure 5 represents the provision and scope of services given or catered with respect the domain of study.
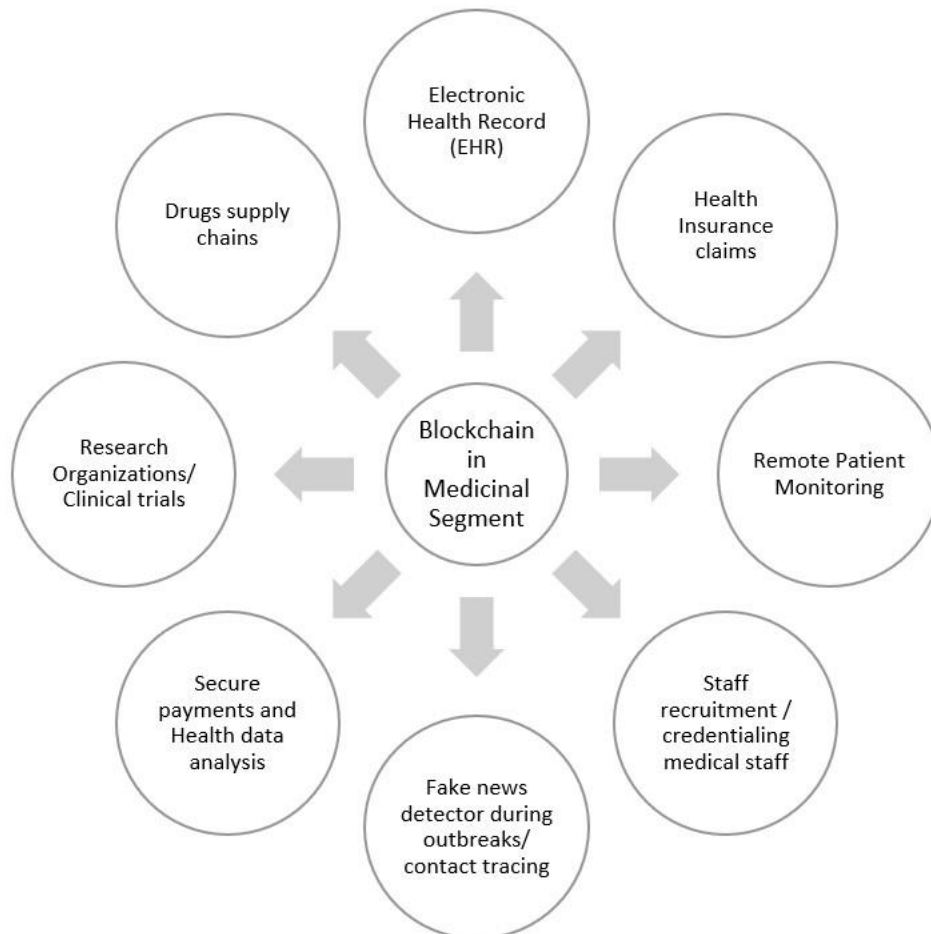
Fig. 5. Scope in healthcare domain

Now, presenting how the system operate without using blockchain and by implementing the recent technology, blockchain.

Services or operations in the field of medicine without Blockchain is as follows:

Medicinal Segment consists of services involving treatment of diseases, clinical, preventive and therapeutic services. It also involves providers including doctors, nurses, care givers, hospitals and other institutions involving services like dental, domestic health, surgical, medical, residential, educational, ambulatory and diagnostic laboratories. It also covers health insurance companies and medical equipment suppliers [3].

- A patient history may lie in fragments in different institutions of medicinal segment. Also, patient cannot access their records in a secure manner.
- Before blockchain medicinal segment work only on centralised systems. This system has limitations that most repositories of patient data are not interacting with each other. Also, with current Hospital Information Systems (HISs) which are cloud based,

data is stored by a single data contractor which can lead to insufficient security and data breaches.

- Counterfeit drugs and fake medicines in the supply chain is a problem in medicinal segment.
- Payment procedures in Medicinal segment are outdated and inefficient that leads to patient's loss, unsatisfaction, mistakes and disputes. This is all due to trust issues especially in the authorization process which some insurance company requires in order pay for services.
- Authorizing and credentialling medical staff members can also be time consuming procedure especially in the need of hour. The certification verification procedures of staff through phone call, mail can utilize a lot of time. An authentication technology can ease this procedure to a great extent.

Services or operations in the field of medicine by using Blockchain is as follows:

- In the digital world and current prevailing conditions of outbreaks, massive healthcare data is generated. Blockchain technology ensures protection of such data while in use and during exchange or sharing over a network.
    - Access to secure data for patients during outbreak such as COVID-19. Blockchain can increase security of health data and patients' privacy [10].
    - Medicinal segment would get better prepared during such outbreak by having relevant information they need in a secure manner about potential outbreak. Misinformation regarding outbreak and vaccines can be handled in an efficient manner [1].
    - Behaviour and impact of outbreaks can be analysed to find a solution though information sharing through blockchain. As well as fulfilling the requirement in situations like continuous obtainability of medicines and health equipment.
    - The distributer ledger technology of blockchain helps in collaboration of various parties to help in analysis and providing insights into vital health trends that can help in handling such outbreaks [10].
    - During outbreaks, solution relying on Bluetooth proximity for geolocation tracking functionality are not efficient in maintaining integrity, security, confidentiality and are vulnerable to hacking that may expose patient information. In such outbreaks blockchain based data tracking applications can easily maintain integrity, security and confidentiality. Possible blockchain technology for this application contains detecting infection spread via decentralized ledgers [1].
- It ensures interoperability with help of which two parties can exchange information in a precise and secure manner without intervention of third party. In medicinal segment this enables a provider to share patient medical records in a secure manner.
- The healthcare providers can share health related information like Electronic Health Record (EHR) to patients irrespective of provider's or patient's place and level of trust among them. Remote patient monitoring that requires gathering of data from patients can be done in a secure manner.

- The security, integrity and data privacy issue are easily handled by blockchain due to its transparent mechanism of working as it eradicates the need for third-party administrators.
- Transparency for pharmaceuticals (supply chain):
    - Blockchain help companies to verify the authenticity of medicines, its manufacturing and expiry dates, its chemical composition and other important information.
    - Blockchain saves time for companies and end consumers of tracking their package's movement from origin till delivery.
    - Blockchain can help in preventing counterfeit prescription medicines and medicinal devices by assuring the authenticity, origin and supply chain of medical products. By integrating manufactures, shipping and warehouses into pharmacy or hospital, a block chain-based system with artificial intelligence and progressive data analytics will help in eradicating the fake medicines supply. The customer can use mobile app for verifying whether the medicine is genuine or not [3].
- Blockchain provide positive Quality of Experience (QoE) for various group of people related to medicinal segment like stakeholders including insurance companies, pharmaceutical companies as well as the end users like patients, researchers, care givers etc [7].
- Blockchain allows transactions and asset to be tracked which facilitates for monitoring and analysing in real-time scenario. A blockchain decentralised ledger supports and speedup the authorisation process, which is the requirement of few insurance companies prior to release of payment for their services. Blockchain speed up the process which require several manual steps and where procedure is complex like in insurance policy for determining the expense coverage of a family member or patient [3].
- Blockchain can help in determining the credibility of a staff member so that one would save time from credentialing information from multitude of repository. With blockchain a safe repository can be created for all members in the chain. By this information related to staff records would be available immediately. This would save one from the repetitive approach and can save time.
- Research organization can use patient's data generated by hospitals to find more solutions to existing health problems, academic research and pharmaceuticals. The blockchain platform allows patients to share their data with research organizations. Through blockchain patients can be provided with incentive for their contribution [1].

4.2 Blockchain Technology employed in medicinal segment

This section summarizes about implementation of blockchain technology by various organizations from medicinal segment. This conveys its usage in electronic health record, remote patients monitoring, pharmaceuticals supply chains, health insurance claims, outbreaks, research organization and clinical trials as follows:
- Gem Health Network uses Ethereum blockchain which helps in providing secure shared access to patient records provided by hospitals [11].

- Guardtime healthcare technology uses Guardtime blockchain for transparency of information sharing in medicinal sector [11].
- Healthcare Level Seven International (HL7) organization developed Fast Healthcare Interoperability Resources: FHIRchain for secure and transparent exchange of medicinal data [12].
- MIT (Massachusetts Institute of Technology) Media Lab and Beth Israel Deaconess Medical Center worked on a project MedRec, that uses blockchain technology to provide patients a platform to give access permissions to any medicinal organization for accessing their EHR data. This process will lead to reduction in paper work carried out by patients when reaching different healthcare providers [13].

Other than these various individual researchers have worked to propose working methods related to blockchain in medicinal segment which is reported in Table 1.

Table 1: Blockchain assistances in medicinal segment

Author	Year	Description	Reference
Liu et al	2018	Proposed blockchain-based Privacy-preserving Data Sharing (BPDS), that uses the Ethereum blockchain platform for secures data sharing in health care.	[14]
Fan et al	2018	Proposed MedBlock, a blockchain-based information management system which offers secure electronic medical data sharing	[15]
Cichosz et al	2019	Proposed NEM multi-signature blockchain contracts for sharing and managing the diabetes patient's data in a secure way	[16]
Nugent et al	2016	Presented Blockchain smart contracts to prevent falsification of data and underreporting of unwanted results of clinical research, which enhances trust in the data and clinical trials.	[17]
Kleinaki et al	2018	Presented blockchain-based notarization service. The service implements smart contracts to seal biomedical database queries. And results offered ensures data transparency.	[18]
Maslove et al	2018	Proposed BlockTrial, that uses Ethereum blockchain technology. This gives web-based interface for users to run trial-related smart contracts on the Ethereum network in clinical data management, thereby enhancing the reliability and transparency of complex data in clinical trials.	[19]
Liang et al	2017	Presented Hyperledger-based implementation of blockchain in mHealth that helps sharing of data in a transparent way.	[20]

Saravanan et al	2017	Proposed SMEAD a secured mobile enabled assisting device for monitoring the patient diabetics.	[21]
Ichikawa et al	2017	Proposed a tamper-resistant mHealth system that uses blockchain technology to securely manage the Electronic Medical Records (EMRs) of patients.	[22]
Bocek et al	2017	Presented a system in pharmaceutical supply chain that uses blockchain technology.	[23]
Zhou et al	2018	Developed MIStore blockchain-based system that uses the Ethereum for medical insurance storage.	[24]
Bhattacharya et al	2019	Proposed a framework BinDasS – Blockchain-Based Deep Learning as-a-Service that combine both blockchain and Deep Learning methods to provide higher security during sharing of EHR records and prediction of disease of patients as future risk.	[25]
Dubovitskaya et al	2020	Developed ACTION- EHR blockchain-based EHR data sharing system built on Hyperledger fabric to ensure patient privacy and security while sharing.	[26]
Hasan et al	2020	Presented a blockchain-based solution using Ethereum blockchain that implements a digital medical identity for COVID-19 test takers to combat false information and tracking using digital medical passports.	[27]
Jabarulla et al	2021	Proposed a conceptual healthcare system based on blockchain and AI to extenuate the challenges of COVID 19.	[28]
Sahal et al	2022	Proposed blockchain, digital twin and Artificial Intelligence based framework for outbreak alerts of COVID-19.	[29]

During COVID-19 pandemic, researcher fraternity includes - Blockchain-Based P2P-Mobile Application Design, Telemedicine and Remote Healthcare Systems, Preventing Fake News Circulation Using MiPasa Platform, COVID-19 Testing Privately Using Epios, Controlling Disease from Expanding Using Anonymous Contact-Tracing-VIRI Platform, Self-Sovereign Identity Using COV-ID and E-Rezept Systems [1].

The succeeding section 5, gives the challenges faced while implementing the blockchain technology in real environment.

4.3 Challenges in Implementation

This section addresses the challenges confronted in implementation of blockchain technology such as:

- Cross-border health data sharing may face problems due to government regulations and different policies may exist depending on different countries [7].
- A large amount of data can lead to mining delays in blockchain. The potential or capability of blockchain in storing and processing massive data needs to be checked. As the transaction will increase in volume for any blockchain there would be delay of mining blocks. New transactions on blockchain may take long time to get verified [4].
- In real world scenario there are mixed communication systems, the working of blockchain in such network requires single global access policy so that blockchain can work properly even with networks owned by different service providers [7].
- A transaction in blockchain requires a block to be created for which computing power needs to be supplied from a network of inter-connected nodes. Thus, blockchain consumes computing power to process transactions and for operating such system a hidden cost is always present as well as an implementation cost. Also, the cost may further increase as the capacity and size of transactions increases [7].
- The practical cost of set up can include the hardware cost, the software cost, the implementation cost, and further support when transitioning any medical segment to blockchain technology. Thus, these cost needs to be assessed and studied in details before transiting [4].
- The blockchain technology does not work efficiently with multi-dimensional data. Thus, we have disadvantage when working for data with high temporal resolution such as complex text and images when using blockchain [30].

5 Conclusion

The blockchain technology has gained and grasped remarkable attention from different organizations, industries, disciplines and researchers. It has potential to revolutionize the traditional services or operations with its astonishing features like decentralization, security, authenticity, streamlining the transactions. It is in practice and predictable that it will restructure the healthcare maintenance system. In this paper, a study has been carried out in line of system without block chain to system with blockchain. With the view point of various stakeholders and services catered by them, a big window is opened for carrying out the research and implementation in real world scenario. It provides the information related to prerequisite required for the implementation along with challenges come across during the implementation. The implementation of blockchain technology will bring comfort to different stakeholders involved in the system.

References

[1] Alsaed, Z., Khweiled, R., Hamad, M., Daraghmi, E., Cheikhrouhou, O., Alhakami, W., & Hamam, H. (2021). Role of Blockchain Technology in Combating COVID-19 Crisis. Applied Sciences, 11(24), 12063.

[2] Yaqoob, S., Khan, M. M., Talib, R., Butt, A. D., Saleem, S., Arif, F., & Nadeem, A. (2019). Use of blockchain in healthcare: A systematic literature review. Int. J. Adv. Comput. Sci. Appl, 10(5), 10.

[3] Mamun, Q. (2022). Blockchain technology in the future of healthcare. Smart Health, 23, 100223.

[4] Blockchain for Healthcare (2021) Leadership for IT Security & Privacy Across HHS Cybersecurity Program. Office of Information Security.

[5] link - https://builtin.com/blockchain. Accessed on 10th Jan 22.

[6] link - https://medium.com/@shyamshankar/centralized-ledgers-vs-distributed-ledgers-layman-understanding-52449264ae23. Accessed on 10th Jan,22.

[7] Khezr, S., Moniruzzaman, M., Yassine, A., & Benlamri, R. (2019). Blockchain technology in healthcare: A comprehensive review and directions for future research. Applied sciences, 9(9), 1736.

[8] Attaran, M. (2020). Blockchain technology in healthcare: Challenges and opportunities. International Journal of Healthcare Management, 1-14.

[9] Khatri, S., Alzahrani, F. A., Ansari, M. T. J., Agrawal, A., Kumar, R., & Khan, R. A. (2021). A Systematic Analysis on Blockchain Integration with Healthcare Domain: Scope and Challenges. IEEE Access.

[10] Abd-alrazaq, A. A., Alajlani, M., Alhuwail, D., Erbad, A., Giannicchi, A., Shah, Z., ... & Househ, M. (2020). Blockchain technologies to mitigate COVID-19 challenges: A scoping review. Computer Methods and Programs in Biomedicine Update, 100001.

[11] Tandon, A., Dhir, A., Islam, N., & Mäntymäki, M. (2020). Blockchain in healthcare: A systematic literature review, synthesizing framework and future research agenda. Computers in Industry, 122, 103290.

[12] Zhang, P., White, J., Schmidt, D. C., Lenz, G., & Rosenbloom, S. T. (2018). FHIRChain: applying blockchain to securely and scalably share clinical data. Computational and structural biotechnology journal, 16, 267-278.

[13] Azaria, A., Ekblaw, A., Vieira, T., & Lippman, A. (2016, August). Medrec: Using blockchain for medical data access and permission management. In 2016 2nd international conference on open and big data (OBD) (pp. 25-30). IEEE.

[14] Liu, J., Li, X., Ye, L., Zhang, H., Du, X., & Guizani, M. (2018, December). BPDS: A blockchain based privacy-preserving data sharing for electronic medical records. In 2018 IEEE Global Communications Conference (GLOBECOM) (pp. 1-6). IEEE.

[15] Fan, K., Wang, S., Ren, Y., Li, H., & Yang, Y. (2018). Medblock: Efficient and secure medical data sharing via blockchain. Journal of medical systems, 42(8), 1-11.

[16] Cichosz, S. L., Stausholm, M. N., Kronborg, T., Vestergaard, P., & Hejlesen, O. (2019). How to use blockchain for diabetes health care data and access management: an operational concept. Journal of diabetes science and technology, 13(2), 248-253

[17] Nugent, T., Upton, D., & Cimpoesu, M. (2016). Improving data transparency in clinical trials using blockchain smart contracts. F1000Research, 5.

[18] Kleinaki, A. S., Mytis-Gkometh, P., Drosatos, G., Efraimidis, P. S., & Kaldoudi, E. (2018). A blockchain-based notarization service for biomedical knowledge retrieval. Computational and structural biotechnology journal, 16, 288-297.

[19] Maslove, D. M., Klein, J., Brohman, K., & Martin, P. (2018). Using blockchain technology to manage clinical trials data: a proof-of-concept study. JMIR medical informatics, 6(4), e11949.

[20] Liang, X., Zhao, J., Shetty, S., Liu, J., & Li, D. (2017, October). Integrating blockchain for data sharing and collaboration in mobile healthcare applications. In 2017 IEEE 28th annual international symposium on personal, indoor, and mobile radio communications (PIMRC) (pp. 1-5). IEEE.

[21] Saravanan, M., Shubha, R., Marks, A. M., & Iyer, V. (2017, December). SMEAD: A secured mobile enabled assisting device for diabetics monitoring. In 2017 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS) (pp. 1-6). IEEE.

[22] Ichikawa, D., Kashiyama, M., & Ueno, T. (2017). Tamper-resistant mobile health using blockchain technology. JMIR mHealth and uHealth, 5(7), e7938.

[23] Bocek, T., Rodrigues, B. B., Strasser, T., & Stiller, B. (2017, May). Blockchains everywhere-a use-case of blockchains in the pharma supply-chain. In 2017 IFIP/IEEE symposium on integrated network and service management (IM) (pp. 772-777). IEEE.

[24] Zhou, L., Wang, L., & Sun, Y. (2018). MIStore: a blockchain-based medical insurance storage system. Journal of medical systems, 42(8), 1-17.

[25] Bhattacharya, P., Tanwar, S., Bodkhe, U., Tyagi, S., & Kumar, N. (2019). Bindaas: Blockchain-based deep-learning as-a-service in healthcare 4.0 applications. IEEE transactions on network science and engineering, 8(2), 1242-1255.

[26] Dubovitskaya, A., Baig, F., Xu, Z., Shukla, R., Zambani, P. S., Swaminathan, A., ... & Wang, F. (2020). ACTION-EHR: patient-centric blockchain-based electronic health record data management for cancer care. Journal of medical Internet research, 22(8), e13598.

[27] Hasan HR, Salah K, Jayaraman R, Arshad J, Yaqoob I, Omar M, Ellahham S. Blockchain-based solution for COVID-19 digital medical passports and immunity certificates. Ieee Access. 2020 Dec 8;8:222093-108.

[28] Jabarulla, M. Y., & Lee, H. N. (2021, August). A blockchain and artificial intelligence-based, patient-centric healthcare system for combating the COVID-19 pandemic: opportunities and applications. In Healthcare (Vol. 9, No. 8, p. 1019). Multidisciplinary Digital Publishing Institute.

[29] Sahal, R., Alsamhi, S. H., Brown, K. N., O'Shea, D., & Alouffi, B. (2022). Blockchain-Based Digital Twins Collaboration for Smart Pandemic Alerting: Decentralized COVID-19 Pandemic Alerting Use Case. Computational Intelligence and Neuroscience, 2022.

[30] Elangovan, D., Long, C. S., Bakrin, F. S., Tan, C. S., Goh, K. W., Yeoh, S. F., ... & Ming, L. C. (2022). The Use of Blockchain Technology in the Health Care Sector: Systematic Review. JMIR Medical Informatics, 10(1), e17278.