

# Towards Health 4.0: Blockchain-Based Electronic Health Record for Care Coordination

Robert Sibanda<sup>1</sup>, Belinda Ndlovu<sup>1</sup>, Sibusisiwe Dube<sup>1</sup> and Kudakwashe Maguraushe<sup>2</sup>

<sup>1</sup>National University of Science and Technology, Bulawayo, Zimbabwe

<sup>2</sup>Mangosuthu University of Technology, Durban, South Africa

[robertsibanda20@gmail.com](mailto:robertsibanda20@gmail.com)

[belinda.ndlovu@nust.ac.zw](mailto:belinda.ndlovu@nust.ac.zw)

[sibusisiwe.dube@nust.ac.zw](mailto:sibusisiwe.dube@nust.ac.zw)

[kuda.maguraushe@mut.ac.za](mailto:kuda.maguraushe@mut.ac.za)

**Abstract:** Inter-organizational data sharing in healthcare is fraught with challenges, including diverse healthcare terminologies, incompatible data structures, and issues with data consistency and security. Establishing a unified patient record across a data-sharing network is problematic, and centralized data stores and authority providers are prime targets for cyberattacks. This study proposes a blockchain-based patient data-sharing strategy that relies on network consensus rather than a single, centralized source of trust. The consensus is based on evidence of both structural and semantic interoperability. The primary objective is to develop secure and controlled data-sharing mechanisms that enhance care coordination. The research utilized Kanban as the software development methodology to manage the project effectively. The study found that blockchain-based electronic health record (EHR) systems significantly enhance care coordination by enabling seamless data transfer and fostering trust and collaboration among healthcare providers. Key findings include improved data consistency, enhanced security, and increased interoperability across diverse healthcare systems. These results suggest that blockchain technology can play a crucial role in transforming healthcare delivery and improving patient outcomes in the context of Health 4.0. This work contributes to the ongoing discussion on leveraging blockchain technology to revolutionize healthcare systems, offering a robust framework for secure and efficient data sharing that can lead to better healthcare delivery and patient care outcomes.

**Keywords:** Blockchain, Distributed ledger, Permissioned, Electronic health record, Health 4.0, Care coordination

---

## 1. Introduction

The integration of digital technologies into healthcare systems, often referred to as Health 4.0 (Radanliev et al, 2020), has the potential to revolutionize patient care, clinical outcomes, and operational efficiencies. Among the emerging technologies, blockchain stands out as a promising solution for transforming electronic health record (EHR) systems and enhancing care coordination. Blockchain technology presents a viable way around the drawbacks of the existing EHR systems. Blockchain is a decentralized distributed ledger system that uses multiple computers to keep track of transactions in a way that prevents tampering and makes the data recorded unchangeable (Ncube et al, 2022). Blockchain technology can protect private medical data from breaches and illegal changes by generating a tamper-proof and secure ledger. By giving people authority over their health information, this promotes trust. Additionally, by bridging the gap between incompatible EHR systems and enabling seamless data transmission between providers, blockchain can enhance care coordination. Ultimately, blockchain can transform EHRs into a more secure, patient-centered, and efficient health information management system (Careline and Godhvari, 2022). The majority of medical data is stored in silos, each having a unique storage architecture and descriptive interpretation (Gupta et al, 2020). Due to this reality, it is challenging to create an interoperable electronic health record exchange or archives or even to easily and securely transmit clinical data to patients, providers, and other stakeholders. Within the same health system, various providers may keep separate sets of patient demographic data. There are redundant tests. There is little prescription data, which raises the possibility of adverse drug reactions. Doctors cannot make treatment suggestions in light of historical circumstances. Data from multiple sources must be manually compiled by population health and case managers to create an accurate picture of a patient's overall health. Since modern technology has advanced so quickly, health institutions have realized how important it is to use and share data. This emphasizes how crucial data privacy is. With the use of blockchain technology, each participant is guaranteed to have a copy of the digital ledger, which is updated instantly as transactions take place. The absence of a centralized server makes hacking all but impossible. The ledger is an unchangeable source of truth since, in theory, a recorded transaction cannot be undone (Careline and Godhvari, 2022). In light of these problems, this research paper proposes a blockchain-based electronic health record (EHR) system aimed at improving care coordination by providing secure and interoperable platforms for sharing patient information among healthcare providers. The objectives of this study are to develop a controlled private data management system using a distributed ledger for capturing patient medical records securely and efficiently. The objectives

of the proposed system are to capture patient medical records, to book appointments for patients, and to view and manage those appointments.

## **2. Literature Review**

Health 4.0 has immense potential to enhance clinical results, patient care, and operational effectiveness. Blockchain is one of the cutting-edge technologies that could completely transform care coordination and electronic health records (EHRs). To improve care coordination, this literature review examines the opportunities and problems associated with deploying blockchain-based EHR systems.

### **2.1 Challenges of Traditional Electronic Health Records**

While there are many benefits to using Electronic Health Records (EHR) in healthcare, there are also specific challenges that must be resolved such as interoperability, data security and privacy, and data quality and integrity. The smooth transfer of health information between various systems is still hampered by interoperability problems (Afza et al, 2021); (Gupta et al, 2020). The communication between various EHR systems is hampered by the lack of defined formats and protocols, which might compromise patient care by causing patient data to become fragmented (Afza et al, 2021). (Afza et al, 2021) raised concerns over the protection of sensitive patient data held in electronic health record (EHR) systems due to persistent security and privacy issues. The reliability of EHR systems is further impacted by the problem of preserving data correctness and integrity. There may be anomalies, errors, and discrepancies in the data.

### **2.2 Blockchain Technology in Healthcare**

Blockchain technology has emerged as a promising solution to addressing the challenges of traditional EHR systems (Afza et al, 2021). Blockchain offers a secured and decentralized system for managing health data, ensuring transparency, integrity, and accessibility while preserving patient privacy. This paper proposed an electronic health record-based which used a distributed ledger to store and manage medical records, records access logs, and access permissions.

### **2.3 Blockchain-Based Electronic Health Records for Care Coordination**

Blockchain technology has demonstrated the potential to address the issues with conventional EHR systems. Blockchain provides a safe, decentralized framework for managing health-related information and protecting patient privacy while guaranteeing accessibility, integrity, and openness. Multiple studies have examined the possible uses of blockchain in the medical field. In their comprehensive assessment of blockchain technology in healthcare, (Durneva et al, 2020)(Jhamba et al., 2024) emphasized how it might improve patient-centered care, interoperability, and data security. Likewise, systematic reviews by and (Hunt et al, 2022) have shown how blockchain technology may be used to secure health data and advance health informatics. Blockchain-based EHR system implementation can significantly enhance care coordination by giving medical professionals access to a safe and reliable environment for exchanging patient data. Through the utilization of blockchain technology, healthcare institutions can ensure the integrity, security, and accessibility of patient data, thereby enhancing care quality and patient outcomes. (Gupta et al, 2020) proposed an interoperable healthcare system using blockchain technology, emphasizing its potential to improve data sharing and care coordination among healthcare providers. Similarly, (Molde et al, 2020) explored the use of blockchain for EHRs, highlighting its ability to enhance data security, integrity, and patient privacy.

While blockchain technology offers significant potential for transforming EHR systems and care coordination, several

challenges and opportunities need to be addressed. (Kiania et al, 2023) conducted a comprehensive investigation of blockchain technology in healthcare, identifying challenges such as scalability, interoperability, and regulatory compliance. However, they also highlighted the opportunities for leveraging blockchain technology to enhance data security, integrity, and patient engagement. (Taherdoost, 2023) carried out a comprehensive examination regarding blockchain technology in healthcare, identifying emerging trends, challenges, and future directions. They emphasized the need for further research and innovation to address the scalability, interoperability, and regulatory challenges associated with blockchain-based EHR systems.

### **2.4 Existing Blockchain Implementations in EHR**

In this section, we discuss various blockchain-based EHR systems, their features, and their weaknesses.

#### *2.4.1 Medrec*

Medrec is an EHR developed by researchers at the Massachusetts Institute of Technology (MIT) for managing Electronic Health Records (EHR). It was designed to address the challenges of data fragmentation, security, and interoperability in healthcare systems (Kiania et al, 2023). Using blockchain technology, MedRec, specifically Ethereum, creates a decentralized and encrypted collection and sharing system for patient health records. Since Medrec is built using Ethereum as the underlying blockchain it takes all the challenges of Ethereum which are the cost of processing transactions and scalability

#### *2.4.2 Medibloc*

MediBloc is a public blockchain platform that has been used to develop an EHR system called MediBloc. MediBloc uses a consortium blockchain architecture and offers features such as data sharing, security, and privacy (Hort et al, 2021). The challenges of Medibloc are scalability and performance. As the number of participants and volume of data on the MediBloc platform increase, scalability, and performance become critical factors. Blockchain systems may face challenges in handling a large number of transactions and maintaining high throughput. Ensuring that the platform can scale effectively to accommodate growing user bases and data volumes is essential for its success (Hort et al, 2021).

#### *2.4.3 GemOS*

GemOS is a blockchain-based operating system designed for healthcare. It allows healthcare providers to securely access and share patient health-related data while ensuring patient privacy and data integrity. GemOS, like other blockchain-based systems, faces scalability challenges (Zhang et al, 2016). As the number of transactions increases, the blockchain becomes slower and more cumbersome to manage.

#### *2.4.4 Patientory*

Patientory is an EHR platform utilizing a distributed ledger that allows patients to manage their health records securely and access them from anywhere. It also permits safe patient information access for medical professionals and communication with patients in real time. Patientory and similar platforms face privacy concerns due to the visibility of all transactions on the blockchain. Protecting patients' sensitive health information becomes challenging (Xia et al, 2017).

#### *2.4.5 Medicalchain*

Medicalchain is a platform that allows patients to store and manage their medical data securely using blockchain technology. It provides patients with full control over who can access their health records and allows for easy sharing of data with healthcare providers. Medicalchain faces scalability challenges (Zhang et al, 2016). As the number of transactions increases, the blockchain becomes slower and more cumbersome to manage. In response to the scalability and privacy challenges identified in existing blockchain-based electronic health record (EHR) systems, this paper proposes a novel solution aimed at addressing these issues and enhancing care coordination in healthcare settings. Building upon the limitations of current blockchain systems, the proposed system presents an innovative approach to securely manage patient data while ensuring scalability, data privacy, and user control. Our solution leverages a private blockchain network to address privacy concerns, ensuring that sensitive health data is securely

stored and accessed only by authorized parties. By using a private blockchain, we can guarantee the confidentiality and integrity of patient information while maintaining transparency and auditability. In addition, our system utilizes multiple chains on the same network and a Proof of Authority (PoA) consensus mechanism to address scalability challenges. By distributing the information across multiple chains and using a more efficient consensus mechanism, we can significantly improve the speed and scalability of the blockchain network, ensuring that it can handle a large number of transactions efficiently.

### **3. Methodology**

This section outlines the process and strategies utilized to achieve the project's goal of creating an electronic health record system using blockchain technology.

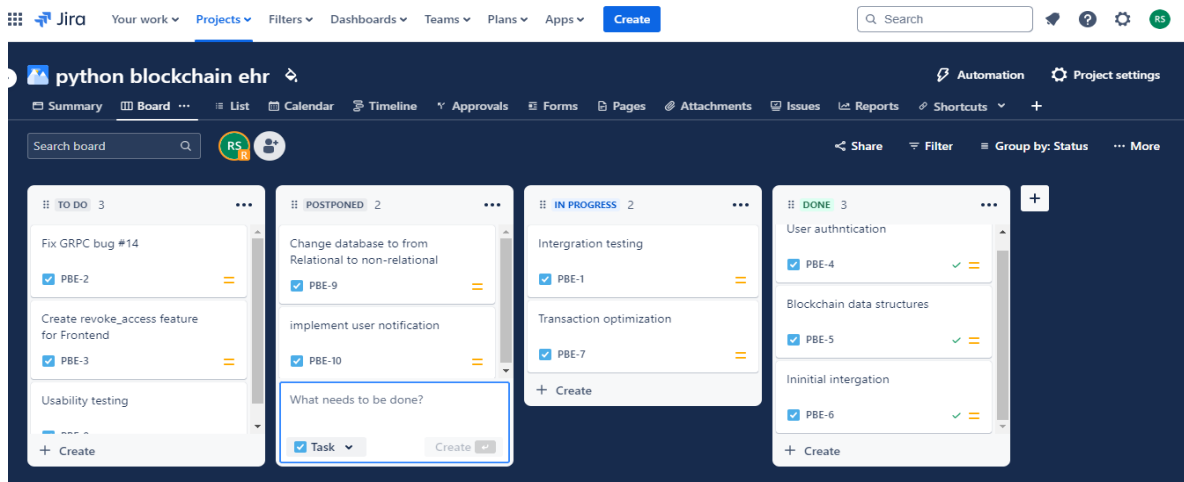
#### **3.1 Research Methodology**

Document analysis was the research methodology used in this study. It is a methodical way of going over and assessing different types of documents, both digital and physical formats. Document analysis is a qualitative

research method that entails carefully reviewing and interpreting data to derive understanding, extract meaning, and produce empirical knowledge (Corbin et al, 2008).

### 3.2 Software Development Methodology

For this research project, we adopted the Kanban methodology as our software development framework. Kanban is a visual and iterative software development approach that emphasizes continuous delivery and workflow optimization. It is based on the principles of visualizing work, limiting work in progress, focusing on flow, and continuous improvement (Anderson, 2010)



**Figure 1: Kanban Board**

In applying the Kanban methodology to our project, we utilized a Kanban board in Figure 1 to visualize our software development workflow. The board consisted of distinct columns denoting the waiting list, work in progress, completed, and testing phases of the development process. Tasks were represented as cards on the Kanban board, and team members were responsible for moving cards across the board as work progressed through different stages. Work-in-progress (WIP) limits were imposed on every step of the process to avoid excessive workload on team members and keep up a continuous workflow. Regular retrospectives were conducted to review the team's performance and identify areas for improvement. Using the Kanban methodology provided several benefits to our project. It improved visibility and transparency into the development process, enabling team members to monitor progress with ease of tasks and identify any bottlenecks or inefficiencies. The visual nature of the Kanban board also facilitated better workflow management and task prioritization, ensuring that the most important tasks were completed first. Overall, the Kanban methodology contributed to increased productivity and efficiency through continuous improvement.

Java was used to create the Android client of the blockchain electronic health record system, while Python was used to develop the distributed ledger and the RPC service that communicates with the Android client. Java is a widely used programming language known for its portability across platforms (Horstmann and Cornell, 2013). Python is a recommended language for blockchain development because of its recognition for readability and simplicity (Lutz, 2013).

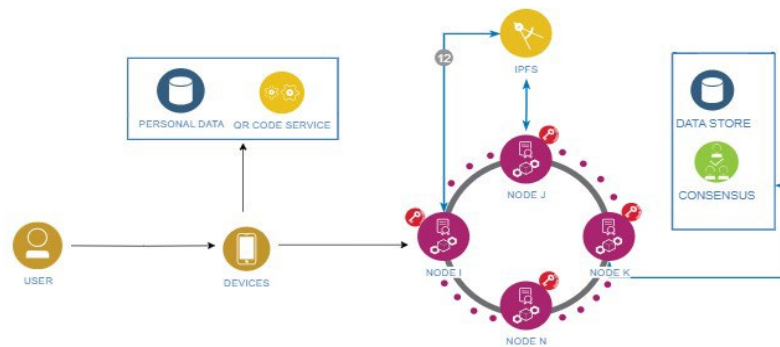
### 3.3 Proposed Blockchain-Based EHR

Our proposed blockchain-based Electronic Health Record (EHR) system is intended to address the challenges of existing EHR systems while also using the benefits of blockchain technology to improve care coordination and patient outcomes. Key features include secure and private storage of patient medical records on a distributed ledger; scalable architecture utilizing a private blockchain network and a Proof of Authority (PoA) consensus mechanism; user-friendly interfaces for both healthcare providers and patients; and advanced security measures such as role-based access control and encryption.

#### 3.3.1 System architecture

As part of the development process, a System Architecture Design is necessary to ensure a well-structured and organized system. Figure 2 shows the private and permissioned blockchain-based electronic health record system architecture, which uses a Proof of Authority (PoA) consensus mechanism.

1



**Figure 2: System architecture**

The blockchain is private, ensuring that data is exclusively accessed by authorized entities within the network. This confidentiality is fortified by robust encryption mechanisms, notably RSA-SHA256, which provides data integrity and security. This encryption standard, widely recognized for its strength, safeguards sensitive health-related information. The system boasts a direct communication channel between the blockchain and mobile clients, facilitated by remote procedure calls (RPC). Personally Identifiable Information (PII) remains securely stored on mobile devices and off-chain databases, enhancing privacy and confidentiality. Patient-controlled access permissions further empower individuals, granting them control over their health data.

### 3.3.2 Functionality

Figure 2 depicts a blockchain-based system architecture for managing personal and health-related data, emphasizing security and distributed consensus. The user interacts with the system through devices that interface with a central data service. A key feature is the QR code service, which allows one person to scan a QR code on the owner's device, granting access to the owner's records. This service ensures secure and convenient access control. The Android application on the user device communicates with a decentralized network of nodes (Node I, Node J, Node K, Node N) that collectively maintain the blockchain. Each node participates in consensus algorithms to validate transactions, ensuring data integrity and consistency across the network. The system leverages the InterPlanetary File System (IPFS) for efficient, distributed data storage, connecting to the blockchain network. The InterPlanetary File System (IPFS) is a peer-to-peer hypermedia protocol designed to make the web faster, safer, and more open (Benet, 2014). Validated data is then securely stored in a dedicated data store, safeguarded by consensus mechanisms. This architecture ensures robust security, decentralized control, and high availability of personal and health data, providing a reliable framework for blockchain applications. Patients get to share their medical information with their care providers therefore, facilitating care coordination. Medical history is permanently recorded in the data store allowing for continued care even after switching care providers or hospital centers.

## 4. Results

This study investigates the development and deployment of a blockchain-based Electronic Health Record (EHR) system as a potential cornerstone for achieving Health 4.0 in healthcare delivery. We present the findings of our research, focusing on the system's performance, functionalities, and its capacity to address limitations inherent to traditional EHR systems. This section delves into the achieved milestones, optimizations implemented, and insights gleaned, emphasizing the transformative potential of blockchain technology within the domain of healthcare informatics.

### 4.1 Transaction Structure Snippet

Figure 3 shows the structure of the transaction that will be stored on the blocks of the blockchain. Each transaction type is stored on a separate chain, for example, permissions and records are stored on different chains on the same or different nodes enabling faster access to information by maintaining smaller spate chains. This makes the network faster in writing and reading transactions from the distributed ledger.

```

6 @dataclass
7 class Transaction:
8     """
9     transaction_type : represents the node-type
10    Not all transactions are stored on all nodes
11    access logs - Node Type 1, access permissions - Node Type 2
12    medical records - Node Type 3
13    """
14    transaction_type: str
15    data: str
16    metadata: str
17    hash: str
18
19    def __post_init__(self):
20        self.hash = create_hash_default(self.data)
21
22    def _from_dict(self, data: dict):
23        self.type = data['type']
24        self.data = data['data']
25        self.metadata = data['metadata']
26        self.hash = create_hash_default(self.data)
27

```

Figure 3: Code snippet showing transaction structure

### 4.2 HashChain Structure

Figure 4 shows that HashChain which will be stored in memory. The actual blockchain data can reach very large sizes which cannot be stored in memory. Storing references of the actual data in memory allows for faster searching and faster data access. The HashChain is also used to verify chains from different nodes to assess if they agree with each other without necessarily copying the whole blockchain and its data.

```

6 @dataclass
7 class HashChain:
8     chain: set()
9
10    def add_block(self, block: HashBlock):
11        self.chain.add(block)
12
13    def find_block(self, block: str):
14        return self.chain.count(block)
15
16    def get_subset(self, o_chain) -> bool:
17        return set(o_chain.chain).issubset(set(self.chain))
18
19    def __le__(self, other):
20        if isinstance(other, self.__class__):
21            return len(self.chain) <= len(other.chain)
22
23    def __lt__(self, other):
24        if isinstance(other, self.__class__):
25            return len(self.chain) < len(other.chain)
26

```

Figure 4: Showing Hashchain structure

### 4.3 User Interface

The electronic health record system has a user interface for doctors and patients. The doctor gets to update and view the patient's records and the patient gets to view their records and give or revoke doctors' access to their records. The doctor and the patient share the same login screen where they enter their account details to access the electronic health record application on their mobile phone or tablet.

#### 4.3.1 The doctor home screen

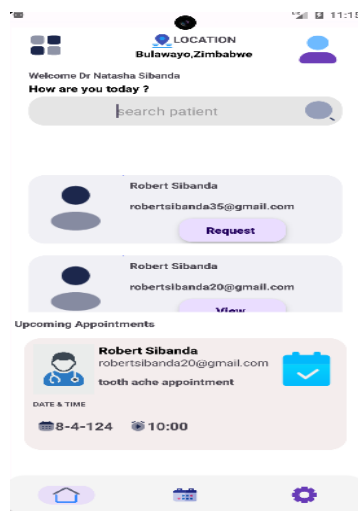


Figure 5: Doctor home screen

The home screen for the doctor is shown in Figure 5 where he/she searches for patients and gets to view or edit their records if he is permitted. The doctor can also view his/her messages and notifications on the home screen. The doctors use the home screen to search for patients. The doctor can also submit a request for accessing patient records. The doctor can also accept or deny appointments from the home interface. All the upcoming appointments will be displayed at the bottom of the interface.

#### 4.3.2 The patient home screen



Figure 6: Patient Home screen

Figure 6 shows the patient home screen where patients can view their doctors, and grant doctors access to their electronic records. The patient by checking or unchecking the View and Update button on a doctor's card can add or remove permissions to a doctor to either view or update their medical records. Appointments will be shown at the bottom of the screen.

#### 4.3.3 Health information screen

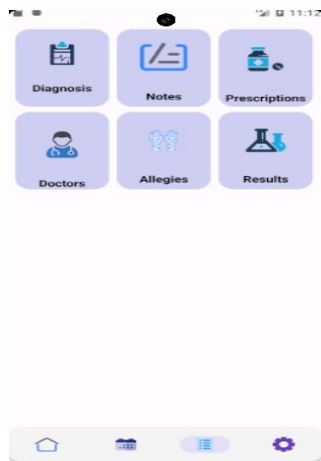


Figure 7: Health information screen

The health information screen in Figure 7 is used to view and update information on the selected patient. The doctor can add prescriptions, notes, alleges, laboratory results interpretations, and diagnoses. This screen can also be used to set an appointment for a patient.

The doctor has less functionality on their health information screen since they cannot add and update their records. They can be able to view their doctors, prescriptions, laboratory results, alleges, diagnoses, and notes from their doctors. Patients can give doctors permission to view and update their records by having them scan a QR code on their device. Doctors that have received permissions through scanning are given temporary permissions and those permissions can be revoked by the patient at any time. The Settings screen is also used to manage privacy and security settings such as changing passwords and enabling password protection of electronic health records.

## 5. Discussion

The results of this study demonstrate that our blockchain-based EHR system successfully addresses the scalability and privacy challenges faced by existing systems. By utilizing a private blockchain architecture and implementing advanced consensus mechanisms, we were able to achieve higher scalability and lower latency, while also ensuring data privacy and security. These findings have significant implications for the future of healthcare informatics and pave the way for the widespread adoption of blockchain technology in healthcare settings.

### 5.1 Performance Optimization Results

Several optimizations were made to improve the scalability and efficiency of the system. By implementing load balancing between nodes and utilizing the PoA consensus mechanism, we were able to significantly improve system performance. These optimizations resulted in higher transaction throughput and lower latency, enhancing the overall scalability of the system. Our proposed system addresses this scalability challenge by implementing sharding and an off-chain storage mechanism. In our system, patient data stored on the blockchain includes only basic patient information along with an IPFS hash. This off-chain scaling solution reduces the volume of patient medical records stored directly on the blockchain.

### 5.2 Proposed Blockchain EHR System Latency

By storing less data directly on the blockchain, our system improves transaction speed as shown in Figure 8, the proposed system can process twice as many transactions per second as other blockchain EHR systems. Additionally, by utilizing IPFS, which stores data in a decentralized manner using a peer-to-peer network, we ensure that our system's security is not compromised while addressing the scalability problem.

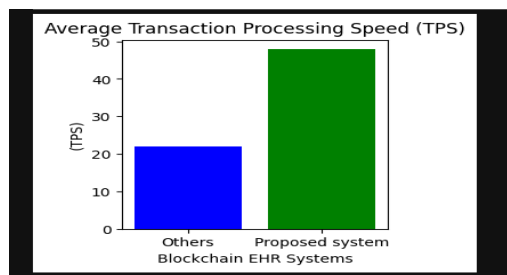


Figure 8: Proposed Blockchain EHR system latency

### 5.3 Challenges

Many Challenges were during the development of the blockchain-based EHR, among these was the imperative to implement robust security measures while concurrently ensuring scalability and speed. Balancing these requirements posed a significant hurdle, as stringent security protocols often impose computational overheads that can potentially hinder system performance. Additionally, maintaining data integrity and privacy amidst the system's expansion presented ongoing challenges. Scalability was crucial to accommodate the increasing volume of transactions and data, requiring careful architectural considerations to prevent bottlenecks and ensure seamless operation.

## 6. Conclusion

In conclusion, implementing an Electronic Health Record (EHR) system using a distributed ledger is a big step toward realizing Health 4.0 and improving care coordination in the healthcare sector. We have dealt with several of the issues associated with standard EHR systems, including data security, interoperability, and data integrity, by utilizing blockchain technology. We can raise patient outcomes, lower costs, and improve treatment quality by offering a decentralized, transparent, and secure platform for exchanging and storing health information. The delivery and management of healthcare will continue to be revolutionized in the future by more research and the use of blockchain-based EHR systems, which will ultimately result in a system that is more effective, efficient, and patient-centred.

## 7. Future Work

Future improvements for the blockchain-based Electronic Health Record (EHR) system outlined in this paper include enhancing the User Experience (UX) and User Interface (UI) design to improve adoption rates among

healthcare professionals and patients. Additionally, integrating the system with innovations such as AI (artificial intelligence) and the Internet of Things (IoT) have the potential to increase its usefulness. Continuously optimizing scalability and performance, establishing interoperability standards, and strengthening data privacy and security measures are essential steps. Real-world implementation and validation studies across diverse healthcare settings, along with cost-effectiveness and sustainability assessments, will provide valuable insights for broader adoption and long-term success. By addressing these improvements, the blockchain-based EHR system can evolve into a more robust, user-friendly, and widely adopted solution for enhancing care coordination and improving patient outcomes in the era of Health 4.0.

## References

- Afza, M., Maqbool, A. and Hussain, T., 2021. Security and Privacy in Electronic Health Records: A Blockchain-Based Approach. *Journal of Medical Systems*, 45(6), doi:10.1007/s10916-021-01745-2.
- Anderson, D.J., 2010. *Kanban: successful evolutionary change for your technology business*. Blue hole press.
- Benet, J., 2014. *IPFS - Content Addressed, Versioned, P2P File System*. [pdf] Available at: <https://ipfs.io/ipfs/QmR7GSQM93Cx5eAg6a6GRhZoWLF6ZWzjoGgsE4oVVpMZRo/ipfs.draft3.pdf> [Accessed 5 Jul. 2024].
- Careline, L.G., & Godhvari, T. (2022). Blockchain Technology for Secure Data Sharing in EHR Systems. *International Journal of Health Sciences and Research*, 12(3), doi:10.5430/ijhs.v12n3p15.
- Corbin, J. and Strauss, A., 2014. *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage publications.
- Durneva, P., Cousins, K. and Chen, M., 2020. The current state of research, challenges, and future research directions of blockchain technology in patient care: Systematic review. *Journal of medical Internet research*, 22(7), p.e18619.
- Gupta, M., Jha, A.K. and Roy, P., 2020. Blockchain technology for ensuring data integrity in electronic health records. *Health Informatics Journal*, 26(2), doi:10.1177/1460458219859312.
- Horstmann, C.S. and Cornell, G. (2013) *Core Java Volume I--Fundamentals*. Prentice Hall Press.
- Hunt, D., McEwen, R. and Lovelock, B., 2022. Blockchain for electronic health records: A systematic review. *Health Policy and Technology*, 11(1), doi:10.1016/j.hlpt.2021.100578.
- Jhamba, P., Mutunhu Ndlovu, B., Dube, S., Maguraushe, K., Kiwa, F., & Muduva, M. (2024, April). A Blockchain-Based Patient Portal For A Mental Health Institution. In 5th African conference on Industrial Engineering and Operations Management, South Africa, <https://doi.org/10.46254/AF05.20240251>
- Kiania, K., Tozzi, A. and Lamanna, G., 2023. A systematic review of blockchain technology in healthcare: Potential and challenges. *Computers in Biology and Medicine*, 147, doi:10.1016/j.combiomed.2022.105672.
- Lutz, M. (2013) *Learning Python*. O'Reilly Media, Inc.
- Molde, H., Sæbø, J.I. and Pedersen, R., 2020. Enhancing data security in electronic health records with blockchain technology. *Journal of Medical Systems*, 44(9), doi:10.1007/s10916-020-01627-7.
- Ncube, N., Mutunhu, B., & Sibanda, K. (2022). Land Registry Using a Distributed Ledger. *2022 IST-Africa Conference (IST-Africa)*, 1–7. <https://doi.org/10.23919/IST-Africa56635.2022.9845584>
- Q. Xia, E. B. Sifah, K. O. Asamoah, J. Gao, X. Du and M. Guizani, "MeDShare: Trust-Less Medical Data Sharing Among Cloud Service Providers via Blockchain," in *IEEE Access*, vol. 5, pp. 14757-14767, 2017, doi: 10.1109/ACCESS.2017.2730843
- Radanliev, P., De Roure, D. and Nurse, J.R.C., 2020. Health 4.0: How Virtualization and Big Data are Revolutionizing Healthcare. *IEEE Access*, 8, doi:10.1109/ACCESS.2020.2982346.
- Taherdoost, H., 2023. Blockchain Technology in Healthcare: Trends, Challenges, and Future Directions. *Journal of Healthcare Engineering*, 2023, doi:10.1155/2023/5542736.
- Worku, M., Edwards, C. and Maier, S., 2023. Blockchain Applications for Health Data: A Survey. *IEEE Transactions on Information Technology in Biomedicine*, 27(2), doi:10.1109/TITB.2023.3054562.
- Zhang, P., Schmidt, D.C. and White, J., 2016. Blockchain Technology Use Cases in Healthcare. *Advances in Computers*, 105, doi:10.1016/bs.adcom.2016.07.002.