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A review of distributed ledger technologies application in medical systems interoperability

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Article info

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Abstract

This study of the literature delves into the complex area of medical systems interoperability, focusing on mitigating variables that impact security and data transfer at the structural and semantic levels. In the era of digital healthcare, the secure sharing of medical data is crucial, and this study looks at how Distributed Ledger Technologies (DLTs) can play a major role in addressing these challenges. Complex interoperability issues that come from differences in communication protocols, data formats, established data structures, data models, and data meaning and codification methodologies face the healthcare industry. These problems typically impede the seamless transmission of electronic medical records between healthcare systems. Because of their decentralized structure and cryptographic foundation, DLTs offer a workable solution to these issues. By critically evaluating previous research and case studies, DLTs may be able to lessen these interoperability issues, as this literature review illustrates. Since DLTs provide an immutable and secure platform for the transmission of medical data, guaranteeing data integrity and confidentiality, they are a natural fit for the sensitive nature of healthcare data. Their importance in creating safe communication protocols, enhancing the meaning of data, and defining models and formats for data is emphasized in this review. A comprehensive architecture for DLT interoperability in healthcare is also recommended by the research. This framework encourages the development of DLT integration, shared data models, standardized data formats, and governance and policy. By implementing this strategy and strengthening secure medical data sharing, healthcare organizations and governments may increase the efficiency, precision, and speed of healthcare delivery. The crucial role that DLTs play in removing the structural and semantic barriers to safe medical systems interoperability is highlighted in the conclusion of this literature review. By adopting DLTs, the healthcare sector may usher in a new era of standardized, safe, and efficient medical data transmission, which will ultimately benefit both patients and healthcare providers. This study shows how distributed ledger technologies (DLTs) have the potential to revolutionize the healthcare industry by enabling the secure and meaningful exchange of medical data between different systems, thereby improving patient care and healthcare outcomes.

Introduction

In the very private and significant healthcare sector, data security, privacy, and interoperability are essential (Kotey et al., 2023). Since secure medical systems are crucial to maintaining the security and integrity of patient data, their significance cannot be overstated. They are also required to enable efficient data transmission be-

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tween various medical facilities and healthcare providers. Safe and efficient data transmission not only enhances patient care but also promotes medical research and public health initiatives (Hasselgren et al., 2020). However, due to differences in data models, communication protocols, and data formats, as well as the need for consistent data definitions and codification procedures, achieving these crucial goals is usually challenging (Chen, 2020).

Secure medical systems (Ajayi et al., 2020; Aljabri et al., 2022; Nagasubramanian et al., 2020; Saxena et al., 2023; Sharma et al., 2022; Yadav et al., 2020) must overcome numerous challenges for interoperability, many of which have both structural and semantic roots. Because different medical systems use different file types, coding schemes, and data structures, the diversity of data formats creates structural issues. These differences in data formats affect the efficiency and accuracy of patient care by making it more challenging to exchange and assess medical data (Ajayi et al., 2020; Aljabri et al., 2022; Gminsights.com, 2019; Kuo et al., 2019; Nagasubramanian et al., 2020; Saxena et al., 2023; Sharma et al., 2022; Yadav et al., 2020). On the other hand, challenges arise at the semantic level due to variations in data meaning and coding methods. When evaluating data, non-standard terminology used by different medical systems and healthcare providers can cause misunderstandings and errors. These challenges increase the fragmentation of medical data landscapes and hinder the safe and timely sharing of electronic medical records throughout the healthcare system.

In this regard, distributed ledger technologies (DLTs) have emerged as a disruptive and intriguing solution (Hasselgren et al., 2020; Kotey et al., 2023; Soltani et al., 2022b, 2022a). A secure, unchangeable, decentralized platform for transferring and storing data is provided by DLTs, most notably blockchain. Healthcare data is particularly well-suited for their cryptographic foundations, which ensure data integrity and confidentiality, due to its sensitive and privacy-focused nature. DLTs present a fresh approach to addressing the complex issues of data security and healthcare interoperability (Bokolo, 2022).

DLTs differ from traditional ledger systems due to its distributed ledger architecture, which stores data over a network of nodes rather than a single repository. Each transaction or data entry is encrypted before being added to the ledger, creating an immutable, transparent record. These features enhance data security by preventing unauthorized access and manipulation and providing an accessible and auditable history of all data transactions. Furthermore, this decentralized structure reduces the likelihood of data manipulation and builds confidence by prohibiting control of data by a single entity.

DLTs offer a great deal of promise to assist with interoperability problems in the healthcare sector, in addition to security. DLTs offer a standardized and safe framework for data interchange, which can promote both structural and semantic interoperability. Healthcare systems, devices, and applications may more easily and cooperatively access, exchange, integrate, and use data thanks to these technologies (Saxena et al., 2023). DLTs provide a standard data structure and codification framework that can facilitate the seamless sharing of electronic medical information among diverse healthcare organizations, regardless of their underlying systems or data formats.

This review aims to provide a comprehensive analysis of the role of DLTs in mitigating the variables influencing safe medical systems, with a focus on both structural and semantic interoperability. This review attempts to shed light on how DLTs might radically revolutionize the administration of healthcare data through an assessment of recent literature, case studies, and industry best practices (Dash, 2023). The goal is to present a thorough analysis of the ways in which distributed ledger technologies (DLTs) can aid in resolving issues with data security and interoperability in the healthcare sector, thereby enhancing public health management, medical research, and patient care.

Healthcare Systems Interoperability

To appreciate the significance of Distributed Ledger Technologies (DLTs) in medical systems, one must first comprehend the challenges associated with interoperability in the healthcare sector. Interoperability is the capacity of diverse information systems, devices, and applications to exchange, integrate, and use data synchronistically and collaboratively (P. Zhang, White, et al., 2018). This connection even transcends corporate, regional, and national boundaries. In the healthcare sector, interoperability is crucial to the prompt and simple mobility of medical information. It enhances everyone's health by facilitating the safe and effective exchange of healthcare data (Olu et al., 2019). The problem of healthcare interoperability is complex and has many facets. Among these are the fundamental, structural, semantic, and organizational layers. The main objective, healthcare interoperability, is something that every level advances by focusing on different aspects of cooperation and data exchange.

Foundational Interoperability: This type of interoperability provides the framework for the exchange of healthcare data (Zetzsche et al., 2021). Establishing the essential framework and specifications needed for secure data transmission are currently the top priorities. It covers necessities like networking, data transit, and security. Foundational interoperability ensures that different systems can communicate with one another and lays the groundwork for more complex types of interoperability.

Structural Interoperability: Building on foundational interoperability, this kind of interoperability examines the smallest details in data flow. It addresses the format, organization, and structure of data (Peterson, Deeduvanu, Kanjamala, & Boles, 2016; Peterson, Deeduvanu, Kanjamala, & Mayo, 2016). This level not only ensures that the data is sent, but also formats it so that the receiving system can understand and use it. Data structures, coding standards, and data formats are a few of the subjects that structural interoperability addresses. Its objective is to create a uniform framework for data interchange, facilitating the comprehension of data from various systems.

Semantic Interoperability: This important phase deals with how everyone involved understands and interprets the data (de Mello et al., 2022; Jaulent et al., 2018; Patange et al., 2021). As of now, the main focus is on ensuring semantic meaning and structural consistency of data transferred between systems. Data definitions, coding schemes, and standardized terminology are used to guarantee consistent and accurate data interpretation. Semantic interoperability eliminates ambiguity and misinterpretation by promoting a common language for healthcare data.

Organizational Interoperability: The highest level of interoperability takes into account governance, policy, legal, and social factors (Macedo & Isaías, 2013; McGovern et al., 2018). It requires coordinating the plans, policies, and practices of numerous healthcare organizations and entities in order to enable safe, effective, and timely data use and communication. Organizational interoperability is essential for enabling shared consent, streamlining end-user workflows and processes, and fostering trust.

The significance of interoperability in facilitating secure exchange of medical data cannot be overstated. Having timely access to accurate patient data is not only convenient, but it is also necessary for delivering high-quality care. Resolving the structural and semantic barriers to interoperability is essential to ensuring that vital medical data can be securely and seamlessly shared across healthcare systems.

Factors Affecting Secure Medical Systems' Interoperability

A complex and multifaceted set of challenges, including data models, communication protocols, data formats, and the need for standardized data definitions and codification techniques, are associated with the interoperability of secure medical systems (Katehakis & Kouroubali, 2019; Urkude et al., 2021). The confluence of these challenges results in an environment where timely and secure electronic medical record exchange remains a significant obstacle.

Data Formats and Their Impact: One of the main challenges to achieving secure medical systems interoperability is the differences in data formats utilized by various healthcare systems (Torab-Miandoab et al., 2023a). These data formats include various file types, coding schemes, and data structures. Many medical systems may use proprietary or institution-specific formats, which greatly complicates the proper interpretation and sharing of data (Yang et al., 2022). For instance, one medical facility might use one particular file type to store patient records, while another might use a different format entirely. The fundamental mismatch brought about by the inconsistent data formats obstructs the efficient exchange of vital medical information.

Communication Protocols and Their Difficulties: The diversity of communication protocols is one of the primary barriers to healthcare interoperability (Kim et al., 2020). Systems, applications, and equipment used in healthcare frequently employ different communication protocols. These protocols may be problematic when systems need to share data without any issues, even though they are often effective in their own domains (Namli et al., 2009). The incompatibilities between these protocols may compromise data security and result in transmission issues. There are several technical challenges as well as issues with medical care related to incompatible communication protocols (Dey et al., 2018). Medical professionals may find it more difficult to promptly obtain vital patient information if there are errors or delays in data transfer (Dwivedi et al., 2019).

Standardized data models and structures: Inconsistent data models and structures plague the healthcare sector, exacerbating interoperability problems. Since medical data is derived from many different systems and sources, it might not conform to standard data models and structures (Le Nguyen, 2018). This lack of conformance makes it difficult to align and integrate data efficiently. Without standard data models, healthcare systems cannot reliably read and use medical data (Alhadhrami et al., 2018). The result is a medical data and information exchange that is ineffective, potentially endangering the timely and high-quality patient care (Hölbl et al., 2018).

Codification schemes and Data Meaning: In the medical field, data meaning is essential. However, when different coding schemes and non-standard terminology are applied throughout healthcare systems, data meaning can occasionally be lost (Benson & Grieve, 2016). Misunderstandings and errors in data interpretation become common when systems employ non-standard terminology or inconsistent codification schemes (Katehakis & Kouroubali, 2019). A diagnosis code in one system might, for instance, indicate something different in another. This discrepancy in the data interpretation could lead to incorrect diagnosis or treatment decisions, which could have major implications for patient care.

The case studies and examples in this section show how these variables affect the safe exchange of medical data in the real world (Haleem et al., 2021; Katehakis & Kouroubali, 2019; Khatoon, 2020; Lehne et al., 2019; Shae & Tsai, 2018; Torab-Miandoab et al., 2023b; P. Zhang, Schmidt, et al., 2018). Real-world examples highlight the complexities and challenges faced by healthcare organizations in their quest for seamless interoperability (Bokolo, 2022; Saripalle, 2019). These issues show how urgently innovative solutions that enhance semantic and structural compatibility are needed. To ensure safe, accurate, and practical patient data interchange across multiple healthcare systems, these issues must be addressed as the healthcare landscape evolves.

DLT Applications for Healthcare Interoperability

This section provides a comprehensive review of the literature on the use of Distributed Ledger Technologies (DLTs) in the healthcare sector, with a focus on easing the challenges associated with secure medical systems' interoperability. The purpose of this literature study is to assess the potential and effectiveness of DLT-based solutions by looking at case studies and research findings that highlight real-world applications.

Successful DLT Applications in Healthcare

Numerous studies have examined the use of DLTs, particularly blockchain technology, to enhance data security and healthcare interoperability (Catalini, 2017; da Conceição et al., 2018; Gordon & Catalini, 2018; Hasselgren et al., 2020; Mangesius et al., 2018; McGhin et al., 2019; Nagasubramanian et al., 2020; Urkude et al., 2021; P. Zhang, Schmidt, et al., 2018; P. Zhang, White, et al., 2018). These applications have shown positive results and provide valuable insights into the potential of DLTs in addressing the diverse problems that the healthcare industry faces.

One prominent example of a DLT application that has worked well in the healthcare sector is the development of blockchain-based electronic health records (EHRs) (Ajayi et al., 2020; Catalini, 2017; Chenthara et al., 2020; da Conceição et al., 2018; Guo et al., 2018; Kim et al., 2020). Blockchain technology can be utilized to provide a uniform and secure platform for electronic health records, according to (Nicole et al., 2020). These blockchain-based EHRs could ensure that medical data is uniformly organized and readily transmitted across healthcare systems by bridging data format discrepancies. Data security, data transfer, and overall patient care have all improved with the deployment of blockchain-based electronic health records (EHRs) (El Ioini & Pahl, 2018).

All of these studies demonstrate the growing interest in the application of DLTs, especially blockchain, in the healthcare industry. The outcomes demonstrate their ability to manage a wide range of problems, such as data integrity, security, and compatibility on both a structural and semantic level. It's important to keep in mind that the effectiveness of these applications can vary depending on the specific implementation and situation.

Challenges and Future Directions

Healthcare interoperability can benefit greatly from the integration of Distributed Ledger Technologies (DLTs), but there are also disadvantages. This section covers the challenges of integrating DLT solutions into healthcare systems as well as fixes for typical issues including scalability, privacy, and regulatory compliance.

DLT implementation Challenges

Scalability: One of the primary challenges to the adoption of DLT in the healthcare sector is ensuring scalability (K. Zhang & Jacobsen, 2018). The amounts of healthcare data are only going to rise, so DLT systems must be able to swiftly handle and process enormous datasets (Kannengießer et al., 2020). Maintaining the inherent security and transparency of DLTs while achieving scalability remains a challenging task (Antal et al., 2021).

Privacy Issues: Despite DLTs' assurance of data security, privacy issues persist. Healthcare organizations must find a middle ground between granting access to data and safeguarding patient privacy (Antal et al., 2021). It is challenging to design DLT systems that safeguard private information while permitting selective patient data access (Chukwu & Garg, 2020).

Regulatory Compliance: The highly regulated healthcare sector has strict requirements for compliance (Zetzsche et al., 2021). Ensuring that DLT-based systems adhere to these regulations can be challenging (GSMA, 2018). It's challenging to take use of DLT technology's benefits while still meeting legal obligations.

DLT Emerging Trends

The disciplines of DLTs and healthcare interoperability are dynamic. This section looks at recent advancements and possible directions in a constantly shifting environment:

Smart Contracts: In the healthcare sector, DLT-powered smart contracts are gaining traction. By automating and enforcing agreement terms, these self-executing contracts simplify administrative processes and enhance the efficacy of healthcare systems (Soltani et al., 2022b, 2022c).

Blockchain Consortia: Collaboration among healthcare consortia is becoming increasingly important. Healthcare organizations are forming consortiums to collaboratively develop and implement DLT technologies, facilitating data exchange and interoperability inside a secure network (Ghosh et al., 2021).

IoT Integration: The convergence of DLTs with the Internet of Things (IoT) is opening up new possibilities for healthcare data management. Data accessibility and integrity can be improved by using DLTs to securely manage the enormous amounts of data generated by Internet of Things (IoT) medical equipment (Almadhoun et al., 2019; Frikha et al., 2021; Reyna et al., 2018; Zaman et al., 2021).

Data Ownership and Control: Future research efforts will most likely concentrate on identifying data ownership and control in DLT-based healthcare systems. Creating protocols that provide patients control over their medical data while preserving data accuracy will be a key focus (Laroiya et al., 2020).

Legal and Ethical Considerations

As DLT-based healthcare systems gain traction, legal and ethical considerations become increasingly important. Respecting healthcare regulations and preserving patient privacy are essential. The ethical use of patient data and transparent consent processes are critical to the success of DLT applications in the healthcare industry (Chukwu & Garg, 2020). Healthcare organizations must strike a balance between data security and moral data practices (Chen, 2020).

The intricacy of the problems pertaining to DLT-based healthcare interoperability is emphasized in this part, along with the importance of staying up to date on new advancements and ethical quandaries in this rapidly evolving field (Chukwu & Garg, 2020).

Conclusion

In summary, this literature review offers a comprehensive examination and perceptive comprehension of the ground-breaking potential of Distributed Ledger Technologies (DLTs) in tackling the problems impacting safe medical systems at the levels of structural and semantic interoperability. A paradigm shift in the medical field is expected with the adoption of DLTs, which offer safe, efficient, and standardized medical data transmission that benefits both patients and healthcare providers. DLTs have the potential to revolutionize the healthcare industry by enabling safe and mutually agreeable medical data exchange between different platforms. As a result, there's a likelihood that healthcare outcomes and patient care will both significantly improve. Given the speed at which technology is developing, it is anticipated that interoperability of medical systems and DLT integration will become increasingly important in the future of healthcare. Strong healthcare interoperability made possible by DLTs may face challenges, but the ultimate objective is to create a setting where patient welfare is given top priority, data flows freely, and healthcare stakeholders collaborate. As this vision eventually materializes, the healthcare sector stands to gain enormously from DLTs' immense potential, ushering in a new era of data-driven healthcare excellence.

Recommendations

This section offers actionable advice for policymakers and healthcare organizations. By putting the recommended DLT interoperability framework into practice and leveraging DLT technology, the healthcare industry may significantly enhance secure medical data sharing and raise the bar, accuracy, and speed of healthcare delivery. Interoperability in healthcare is significantly impacted by the integration of DLT-based technology. By addressing interoperability concerns head-on, the healthcare sector can lower errors, streamline operations, and deliver more efficient, patient-centered care. These ramifications extend beyond data exchange and into an area where the healthcare ecosystem collaborates and operates more effectively. Healthcare organizations and legislators who embark on the DLT adoption journey will have the chance to usher in a time when patient welfare is given ever-greater importance and healthcare systems collaborate well.

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